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Kuramochi et al.

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(45) **Date of Patent: Dec. 13, 2016**

(54) LIQUID DROPLET FORMING APPARATUS

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May 29, 2015 (JP) 2015-109677
Oct. 9, 2015 (JP) 2015-200822

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B41J 2/14 (2006.01)

(52) **U.S. Cl.**
CPC *B41J 2/14233* (2013.01); *B41J 2/14201* (2013.01); *B41J 2202/15* (2013.01)

(58) **Field of Classification Search**
CPC .. B41J 2/14201; B41J 2/14233; B41J 2/14298
See application file for complete search history.

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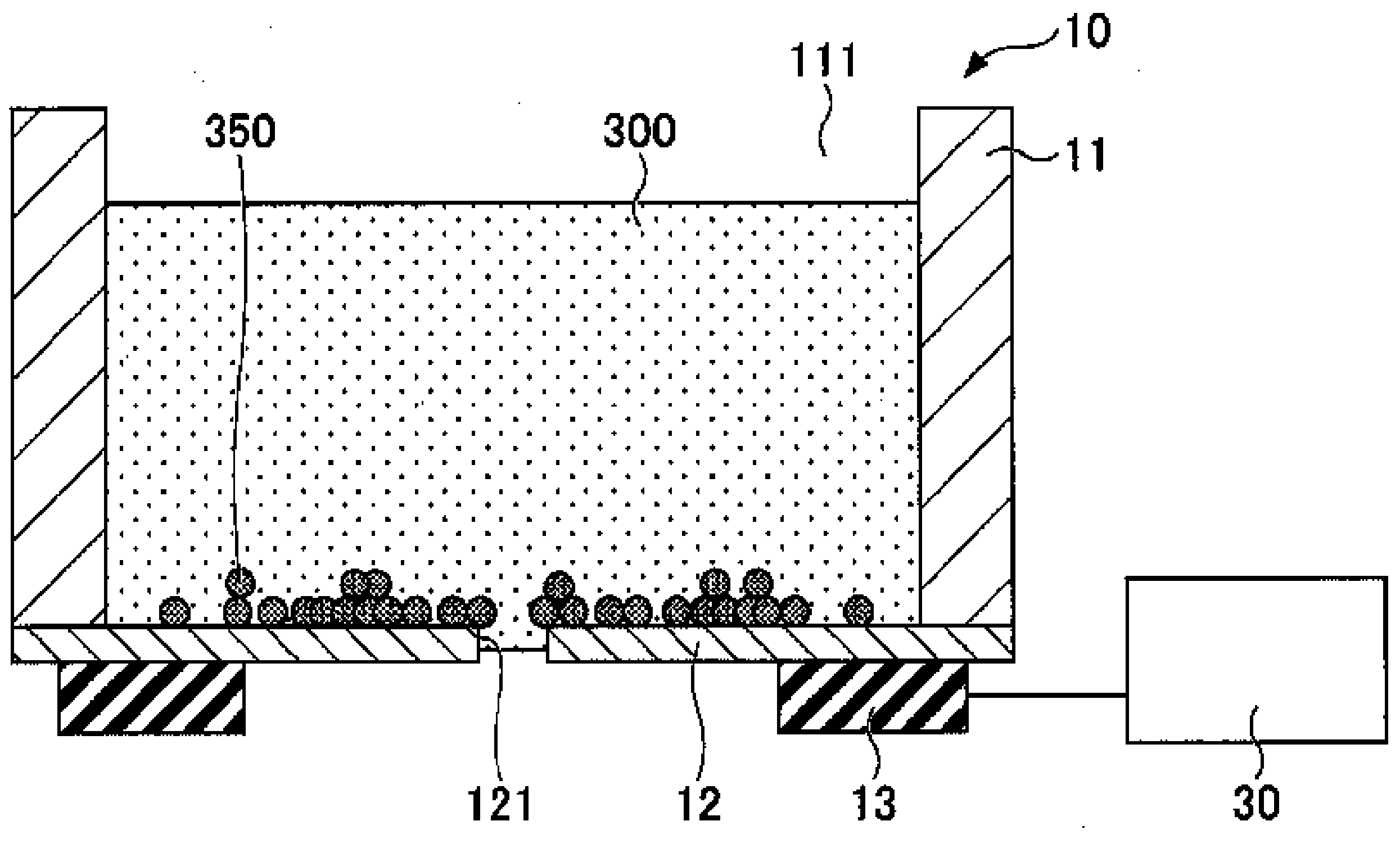
(74) *Attorney, Agent, or Firm* — IPUSA, PLLC

(57) ABSTRACT

There is provided a liquid droplet forming apparatus comprising: a liquid holding part configured to hold a liquid including precipitating particles; a film member configured to be vibrated so as to eject the liquid held in the liquid holding unit, wherein a nozzle is formed in the film member and the liquid is ejected as a droplet from the nozzle; a vibrating unit configured to vibrate the film member; and a driving unit configured to selectively apply an ejection waveform and a stirring waveform to the vibrating unit, wherein the film member is vibrated to form the droplet in response to applying the ejection waveform and the film member is vibrated without forming the droplet in response to applying the stirring waveform.

7 Claims, 19 Drawing Sheets



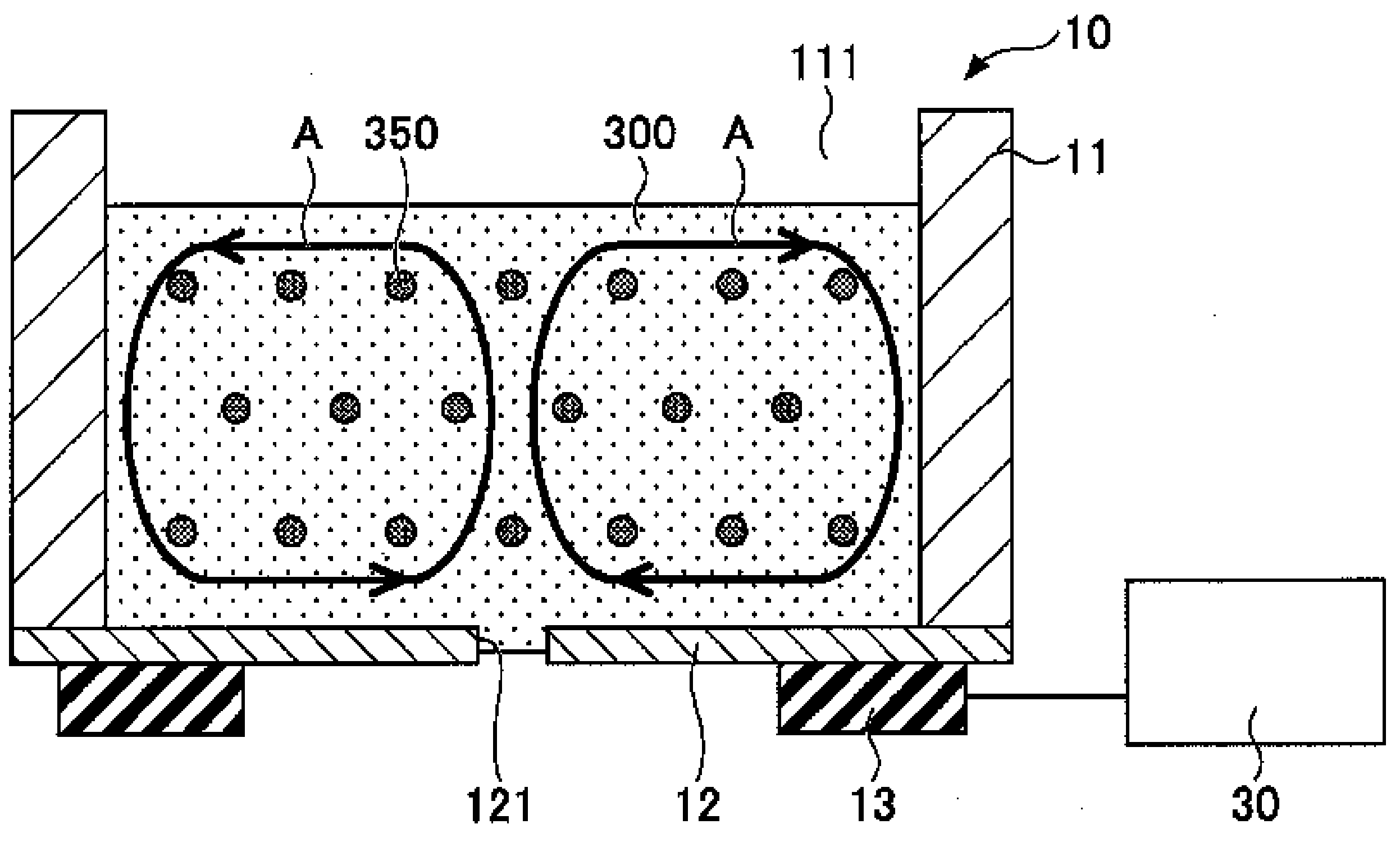


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FIG.1

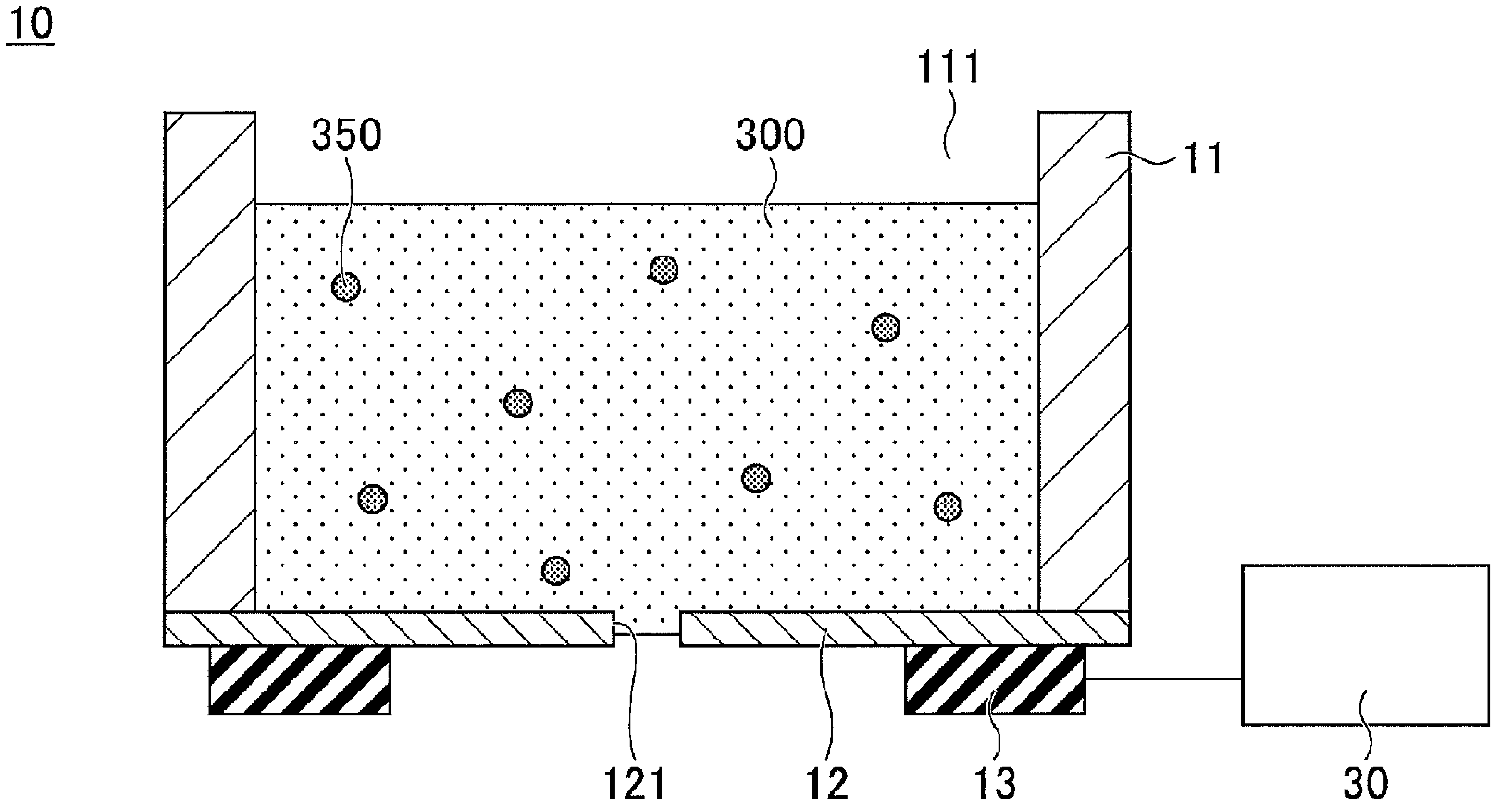


FIG.2

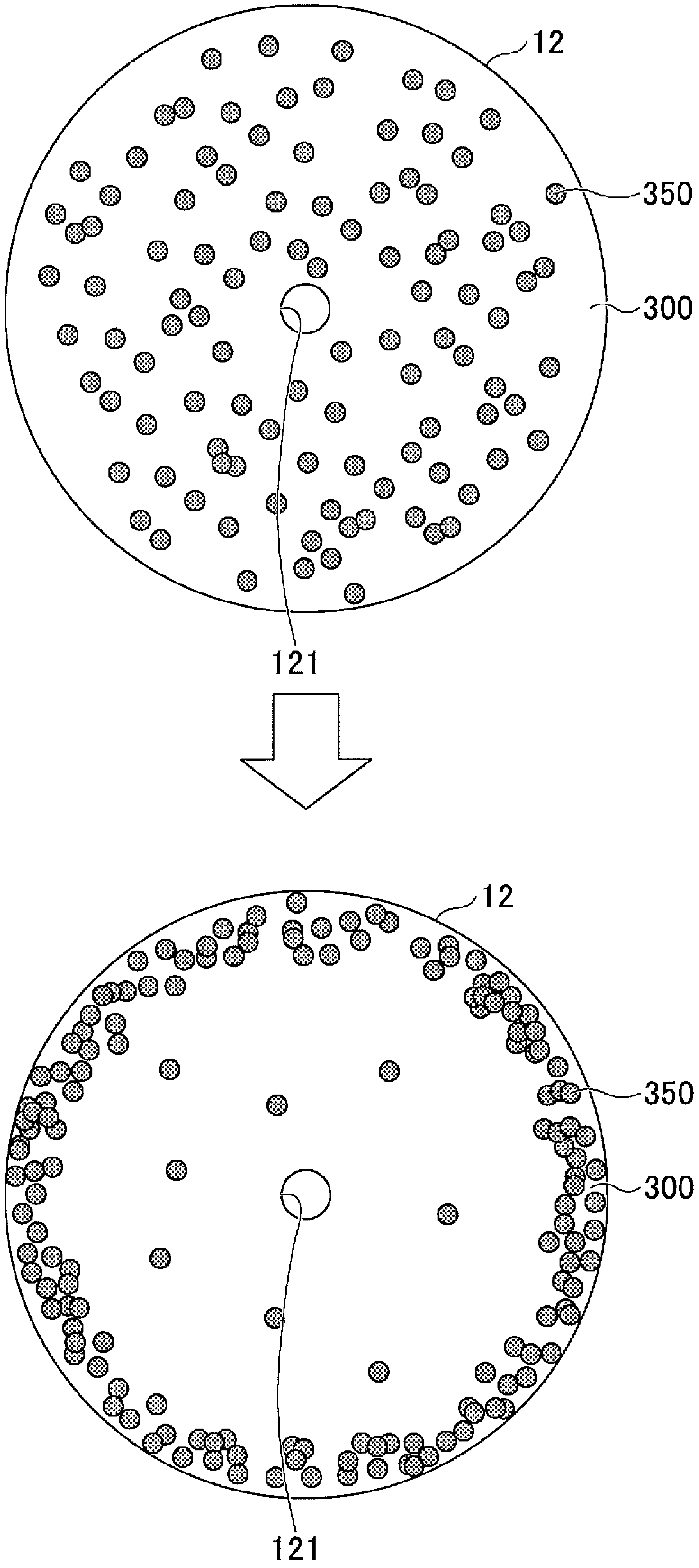


FIG.3A

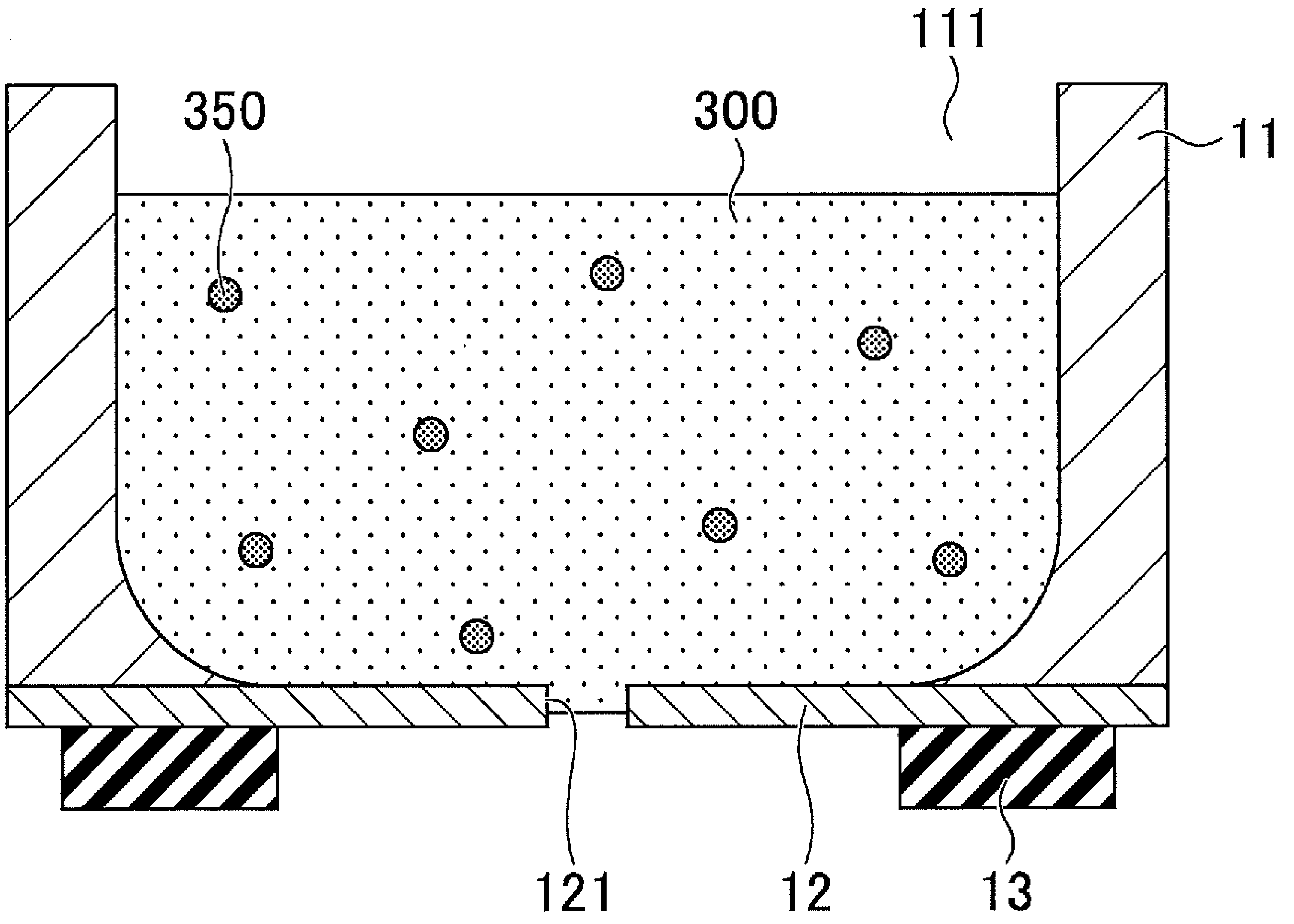


FIG.3B

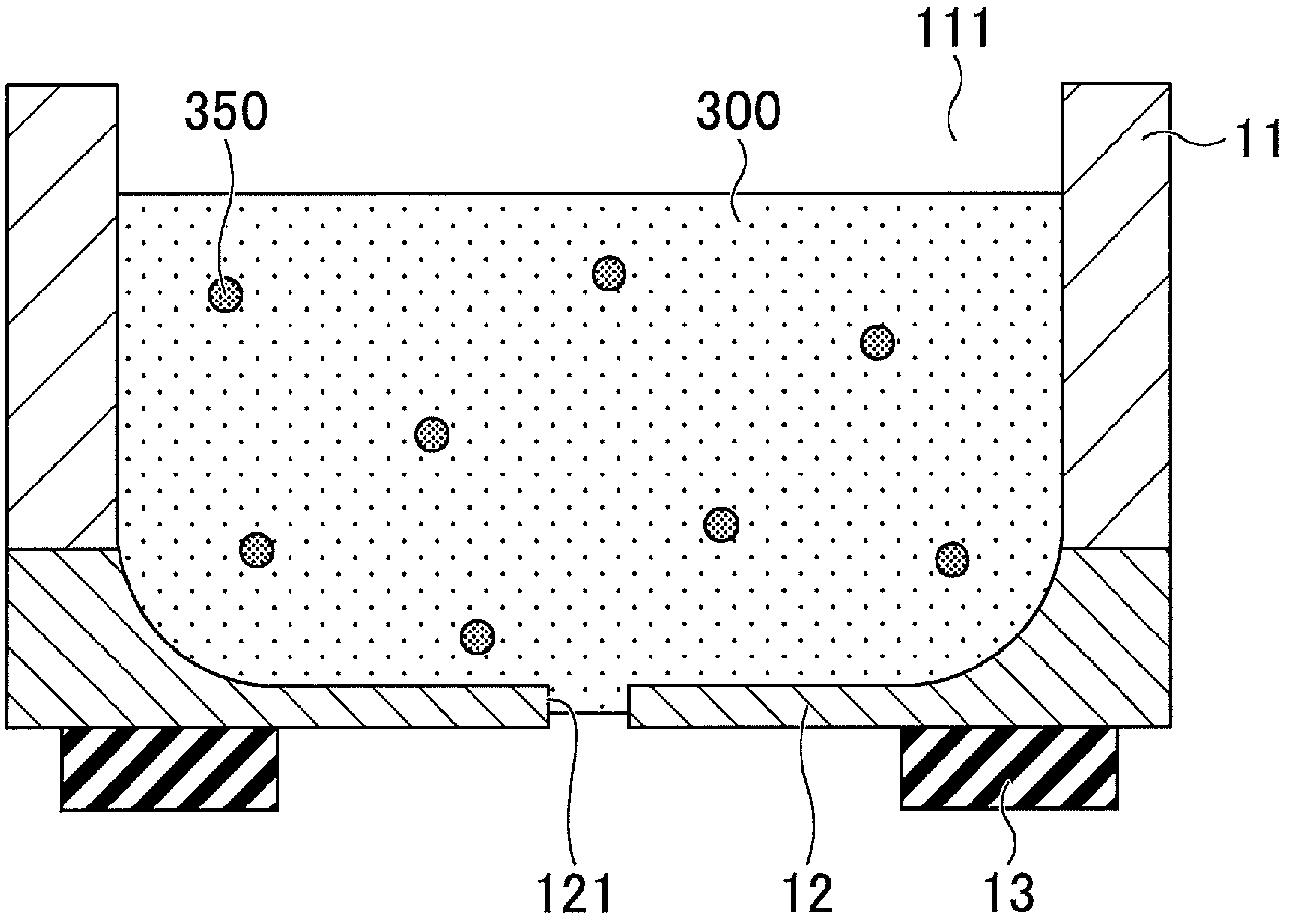


FIG.4A

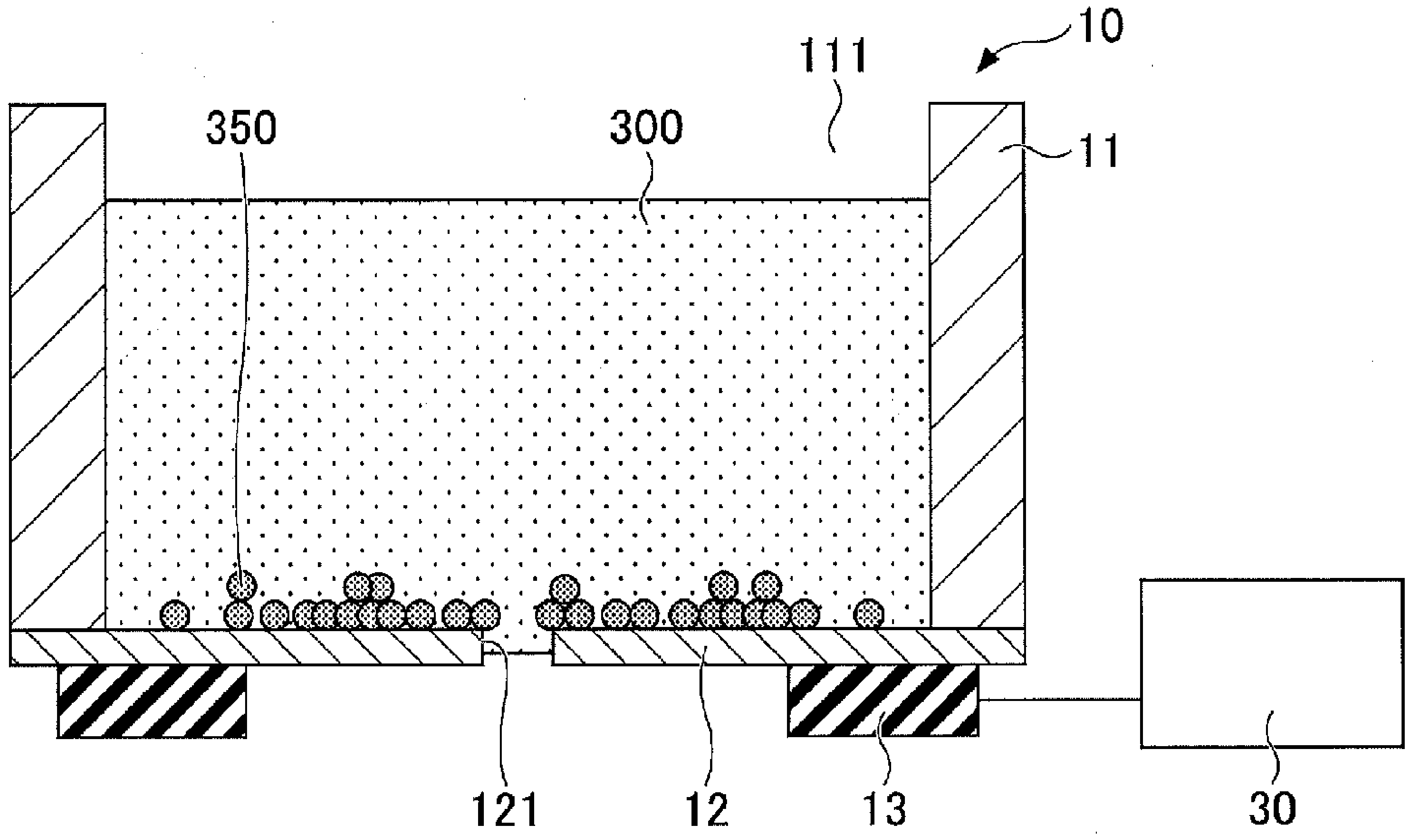


FIG.4B

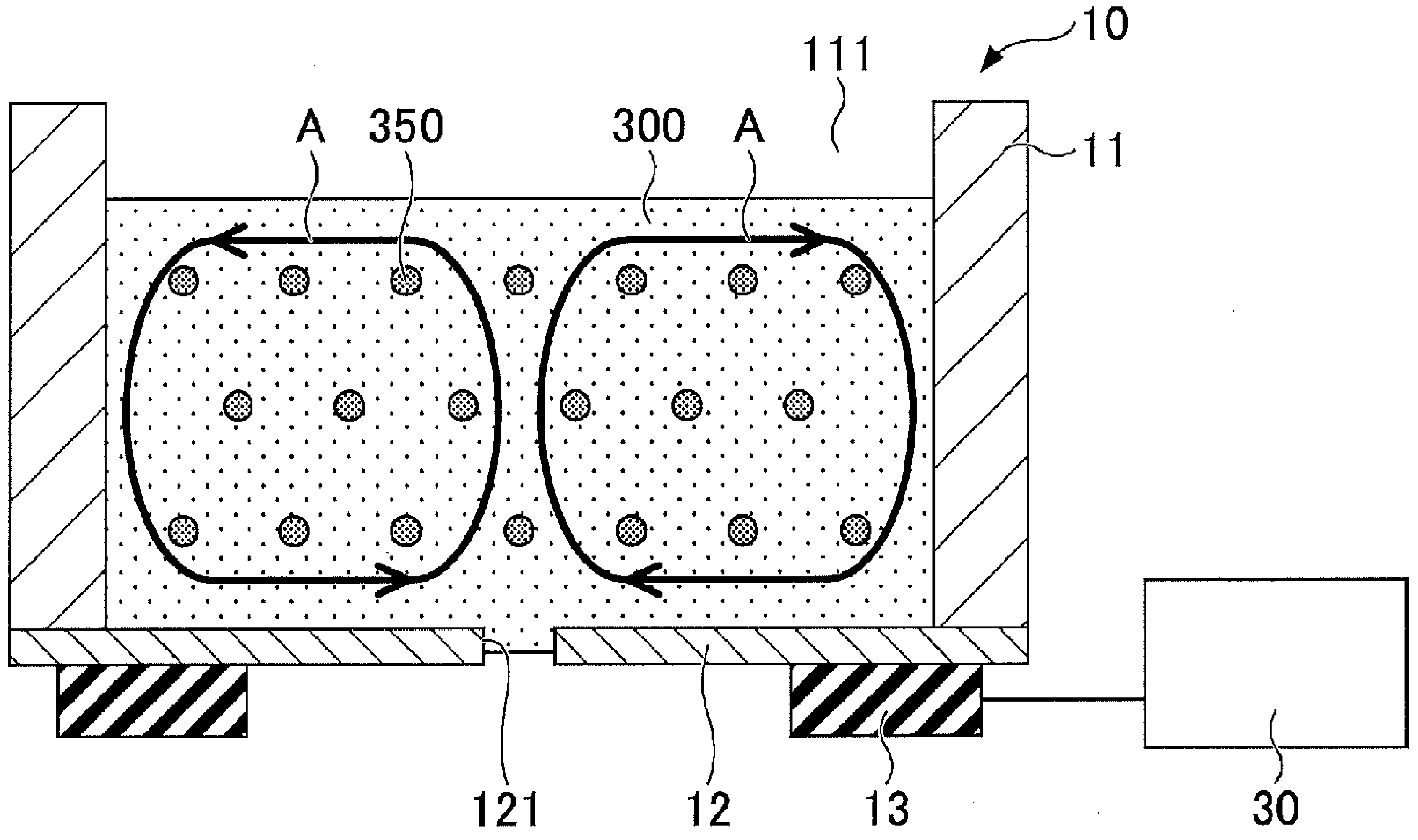


FIG.4C

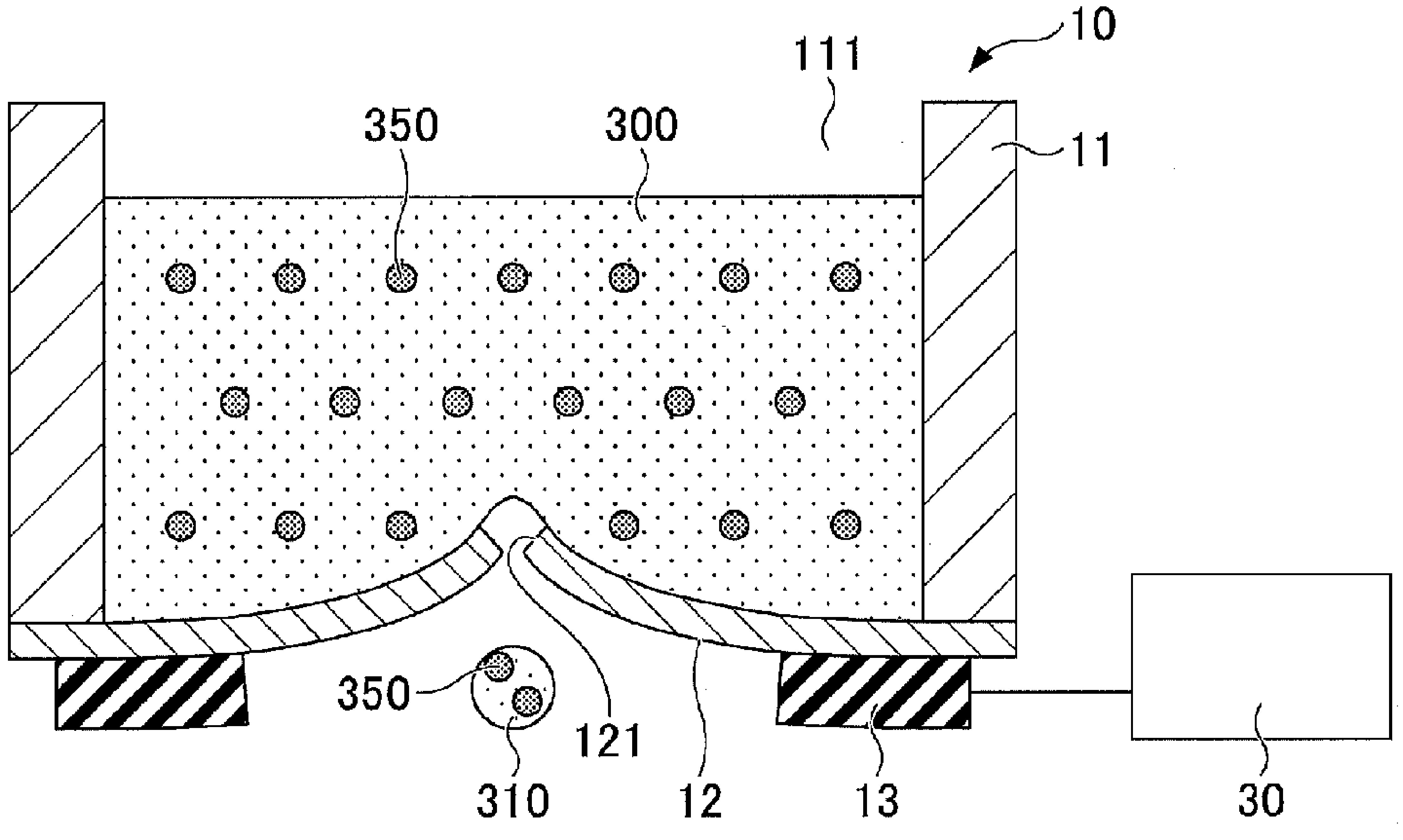


FIG.5A

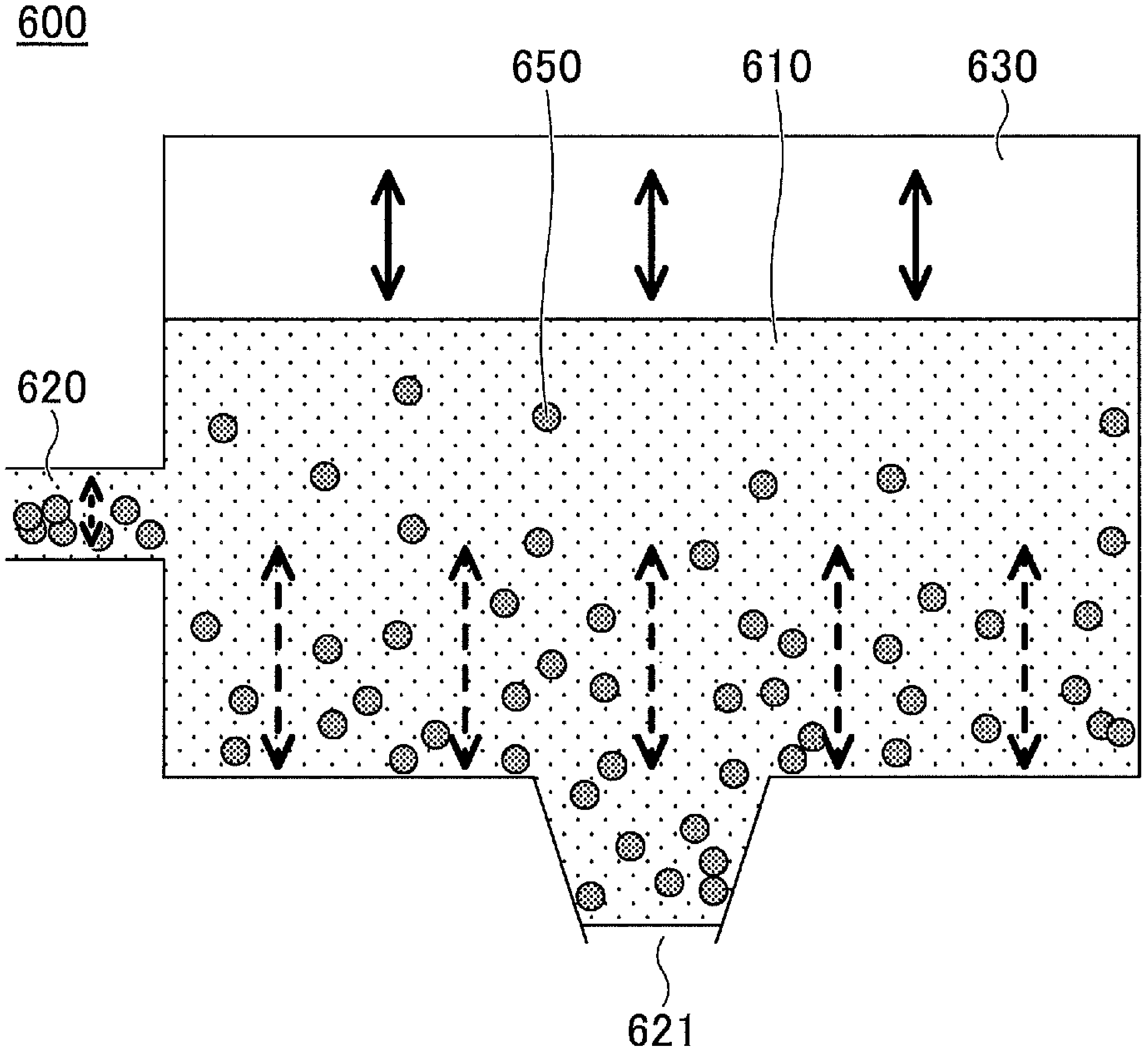


FIG.5B

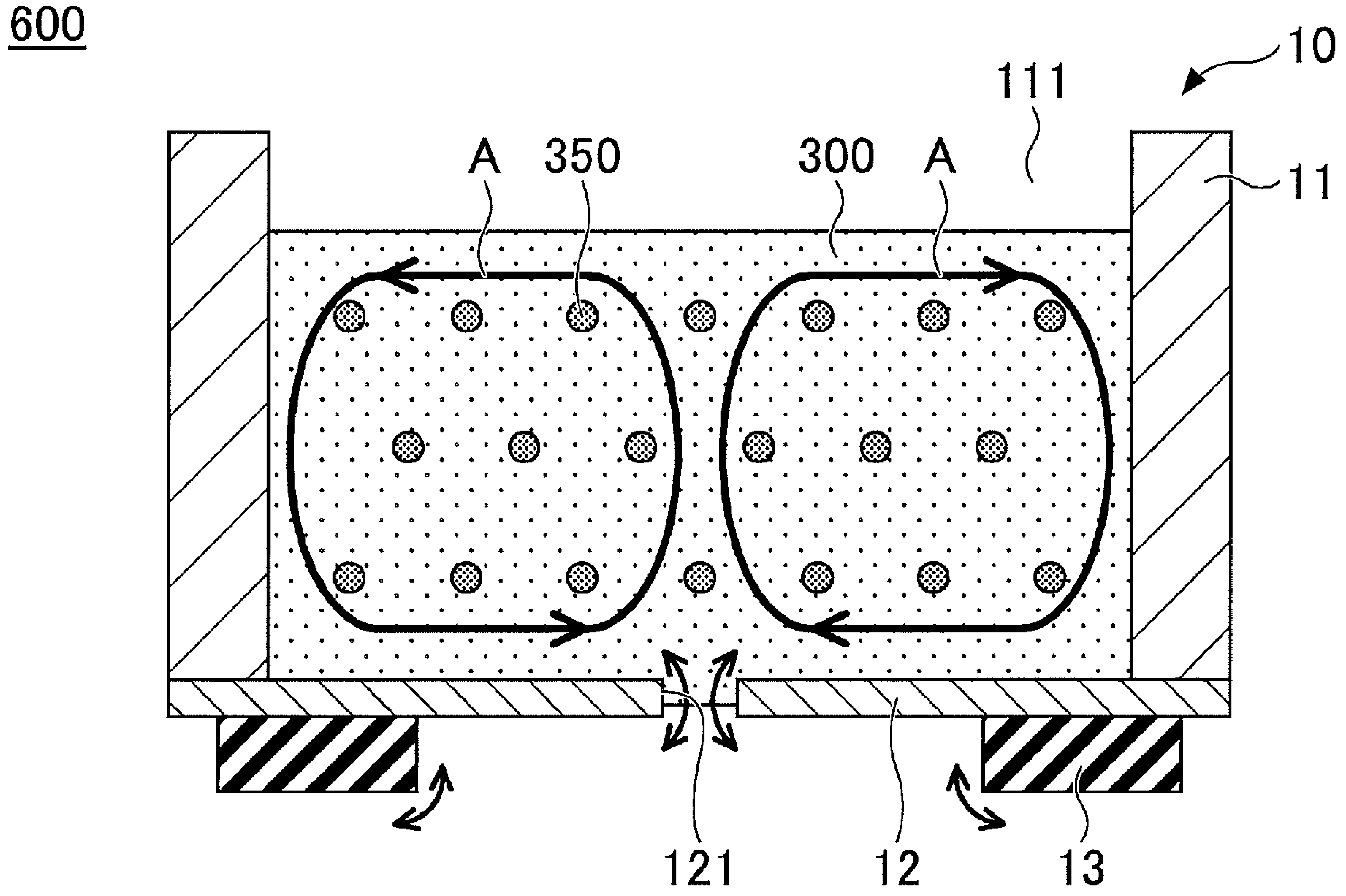


FIG.6

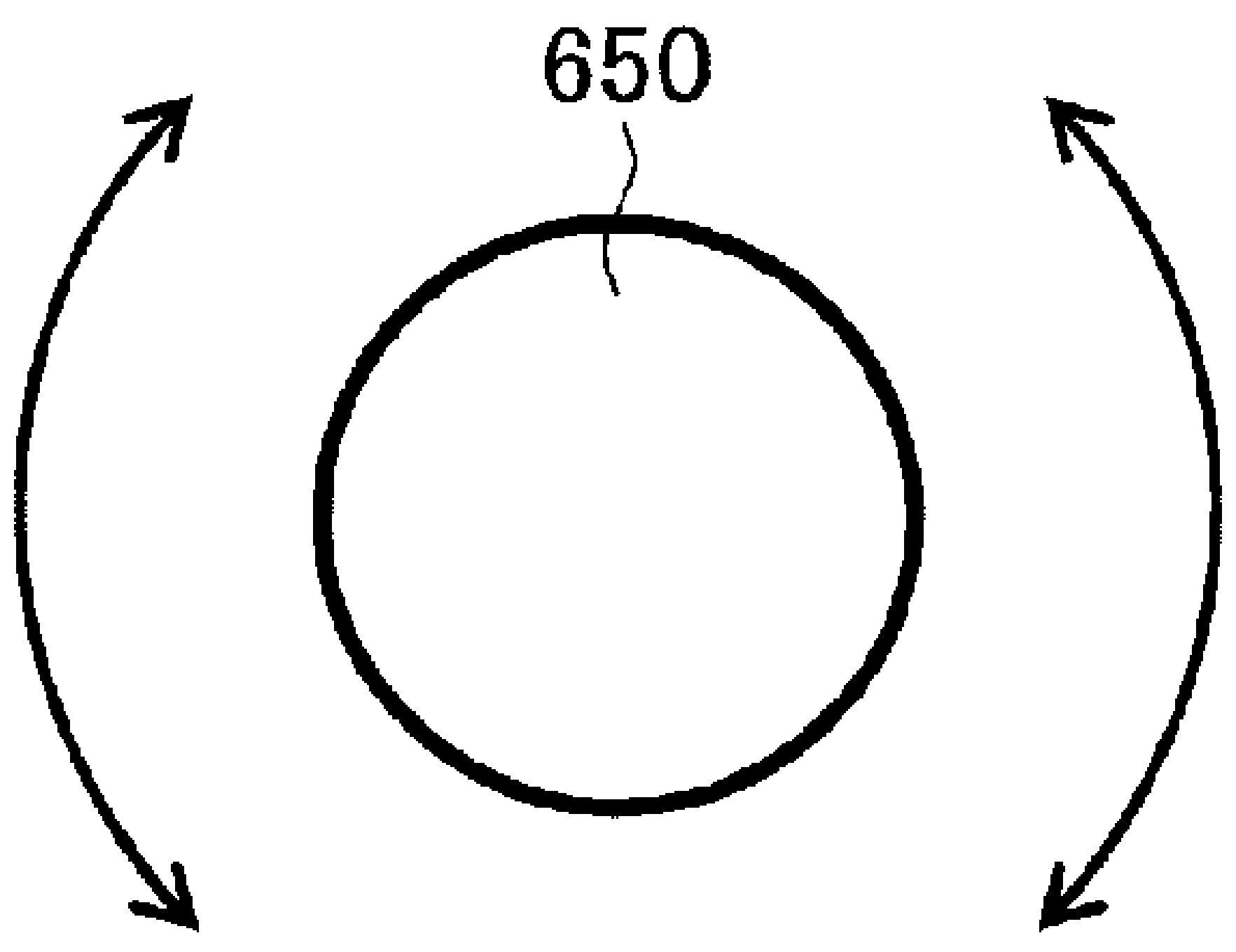
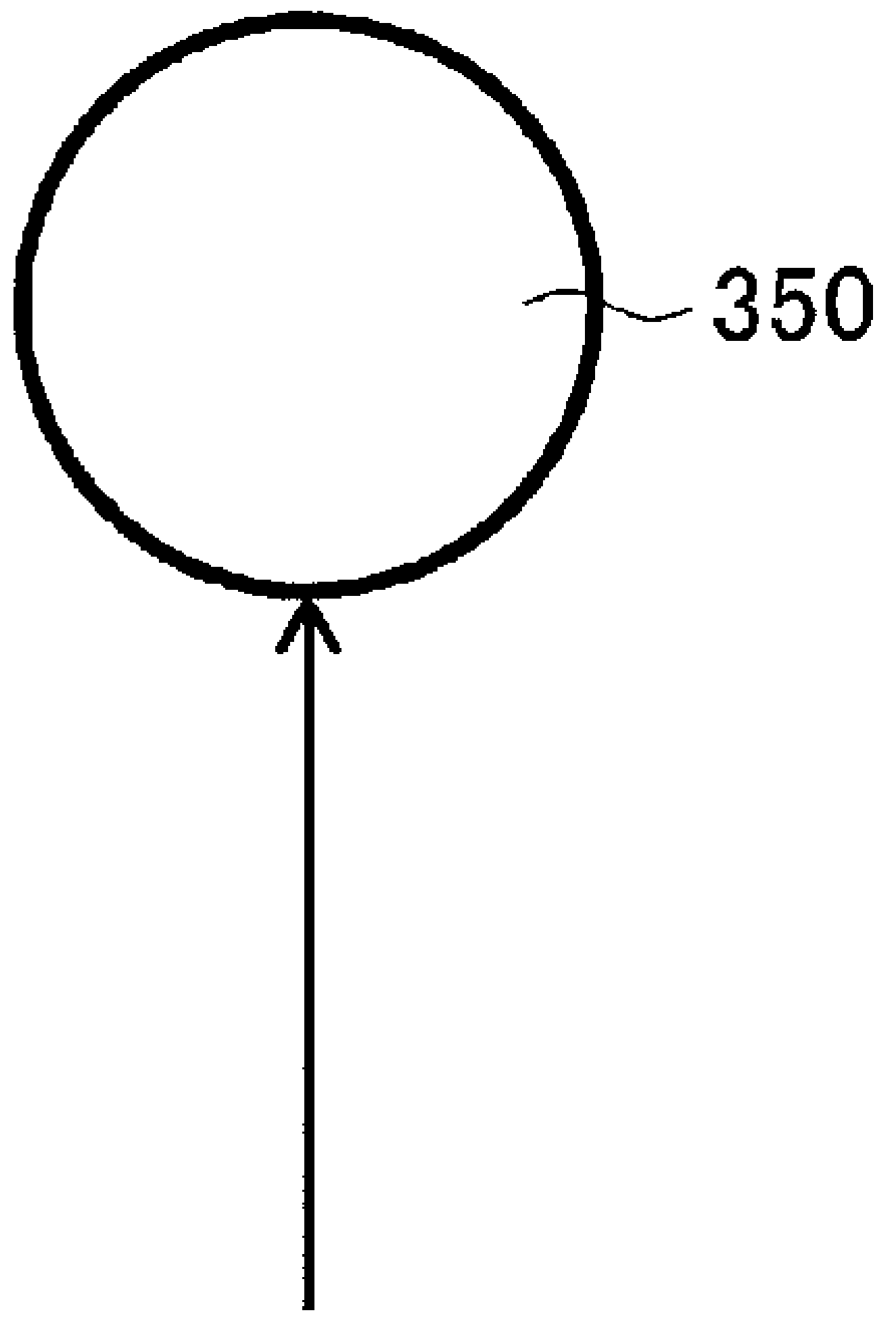
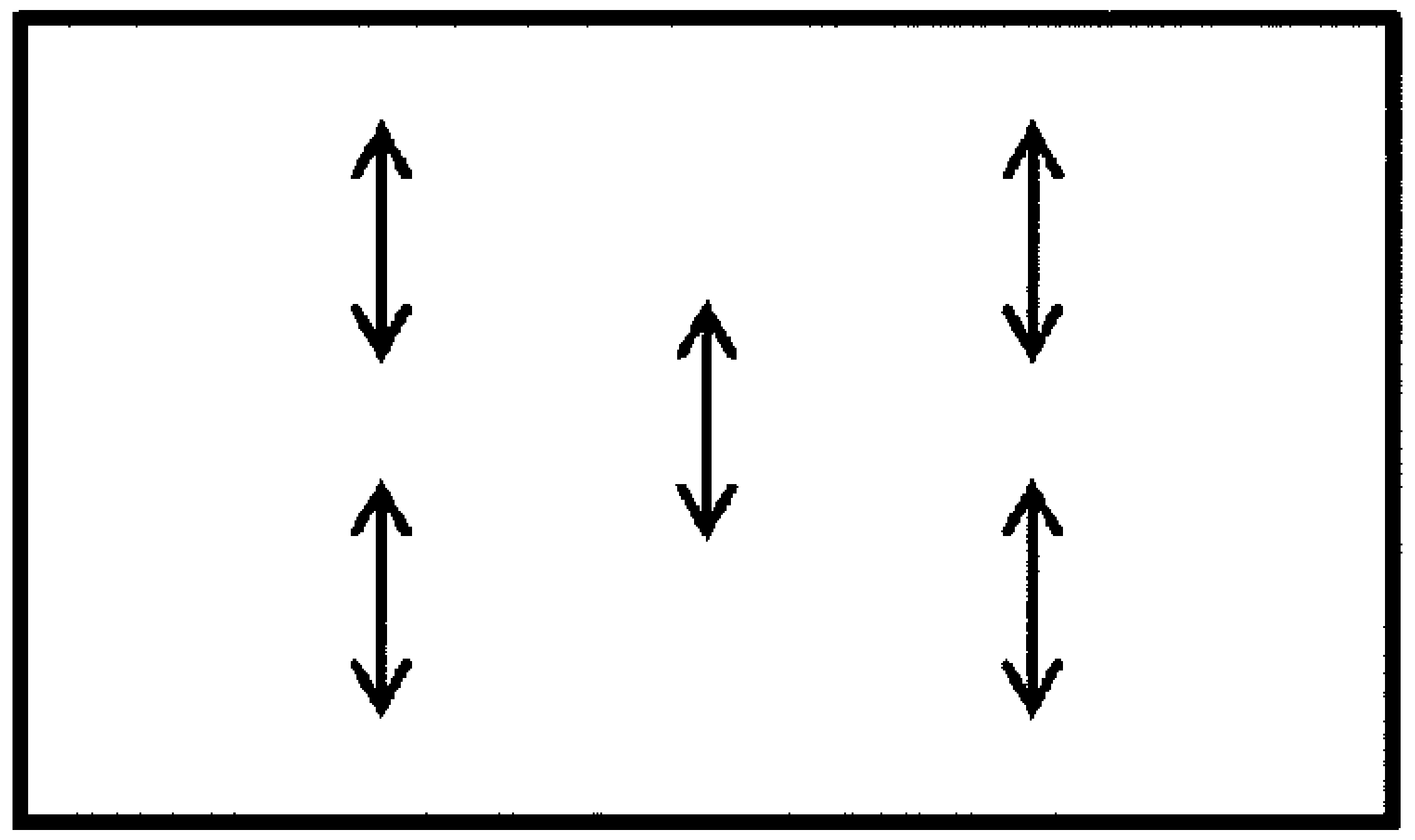
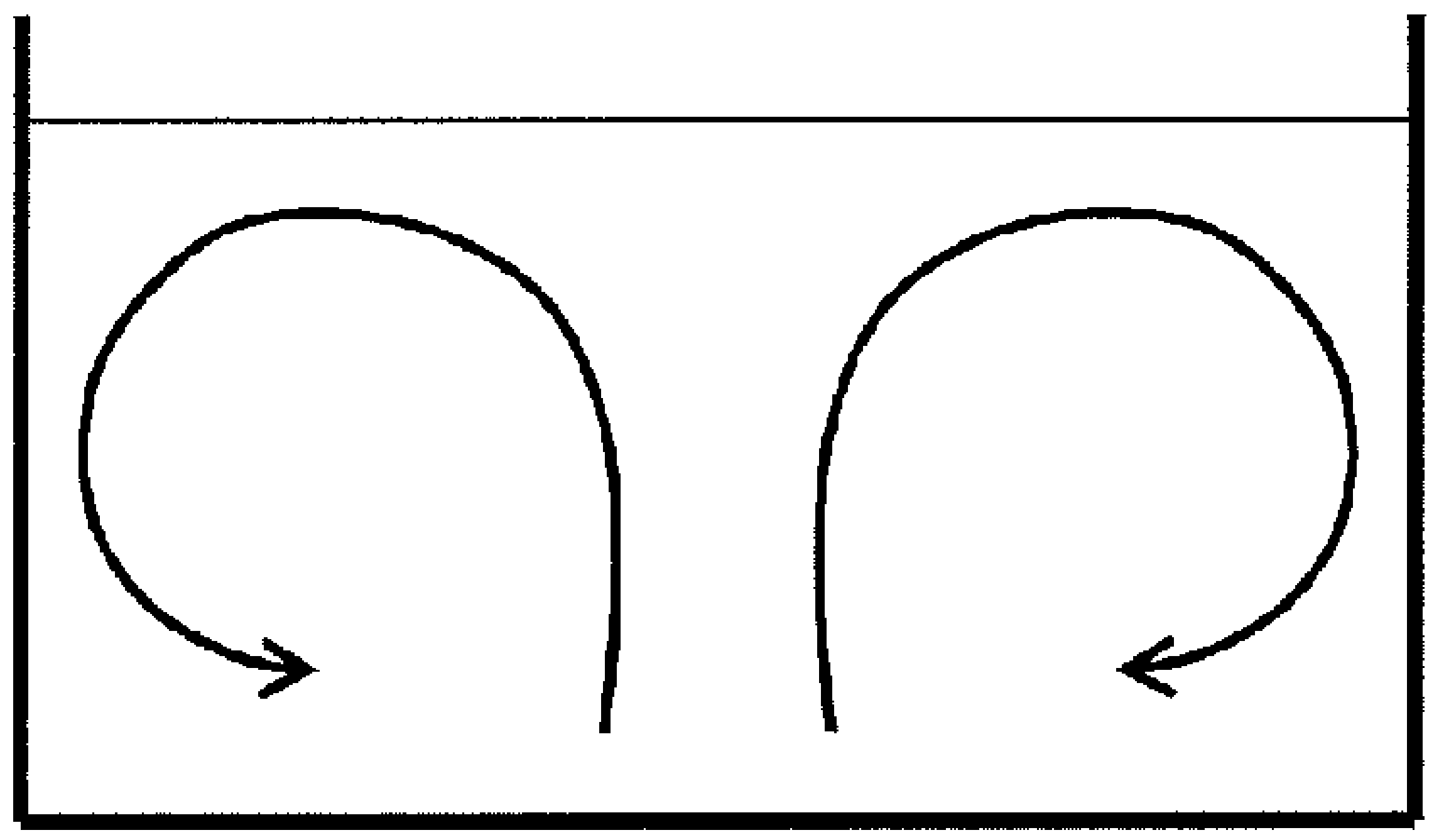
	LIQUID DROPLET FORMING APPARATUS 600	LIQUID DROPLET FORMING APPARATUS 10
MOTION OF A PARTICLE		
MOTION OF PARTICLES IN ENTIRE LIQUID CHAMBER	VIBRATION 	FULL STIRRING 

FIG.7

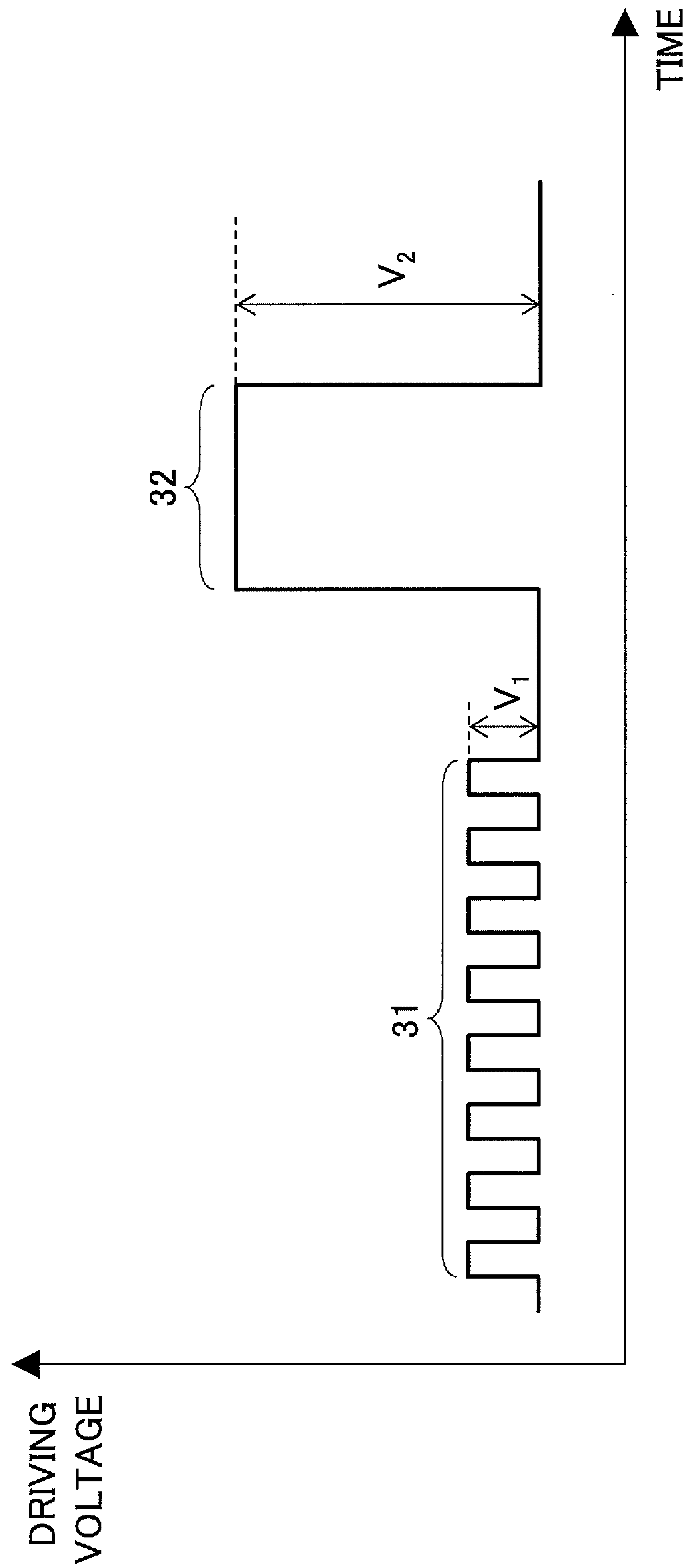


FIG.8

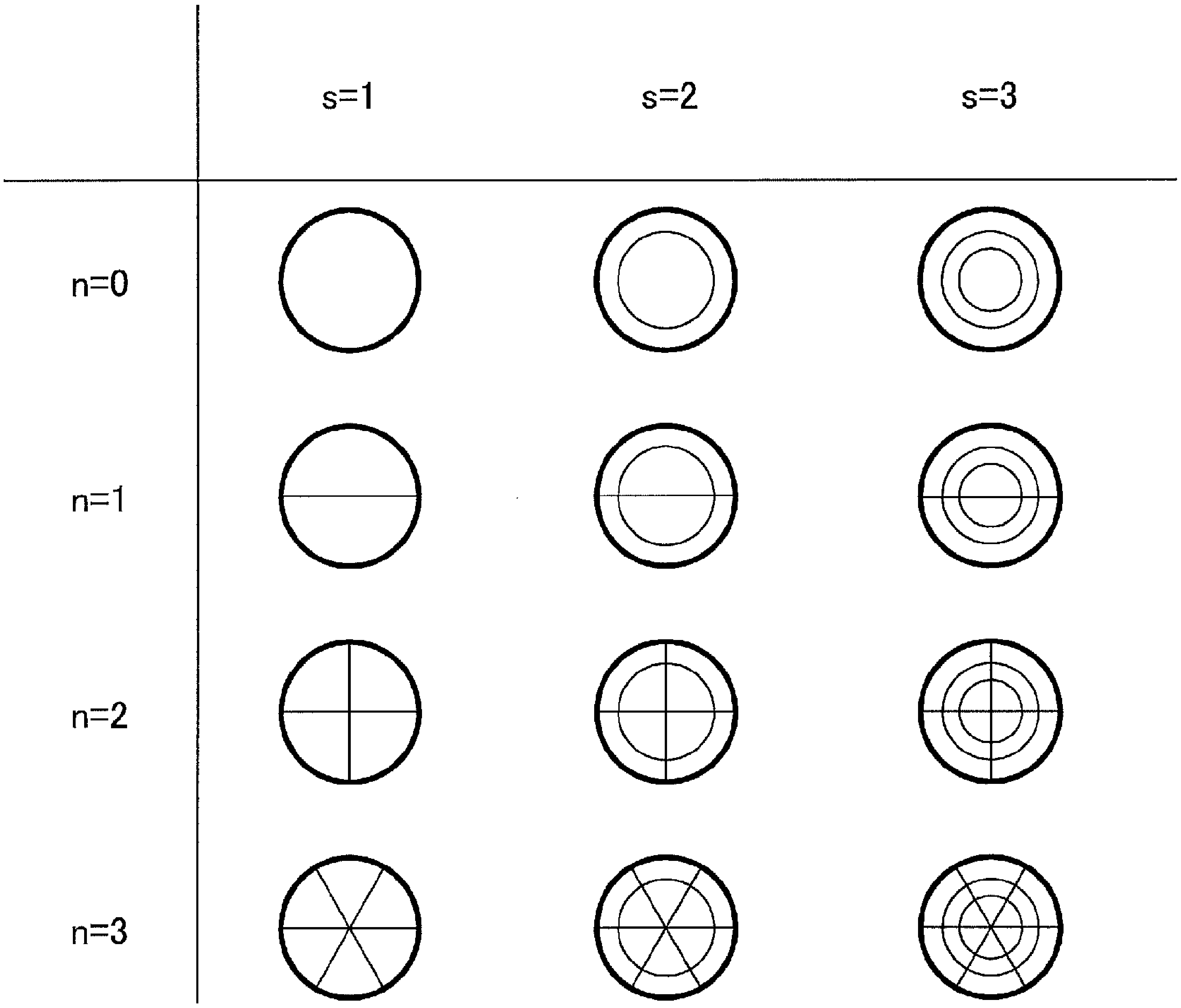


FIG.9A

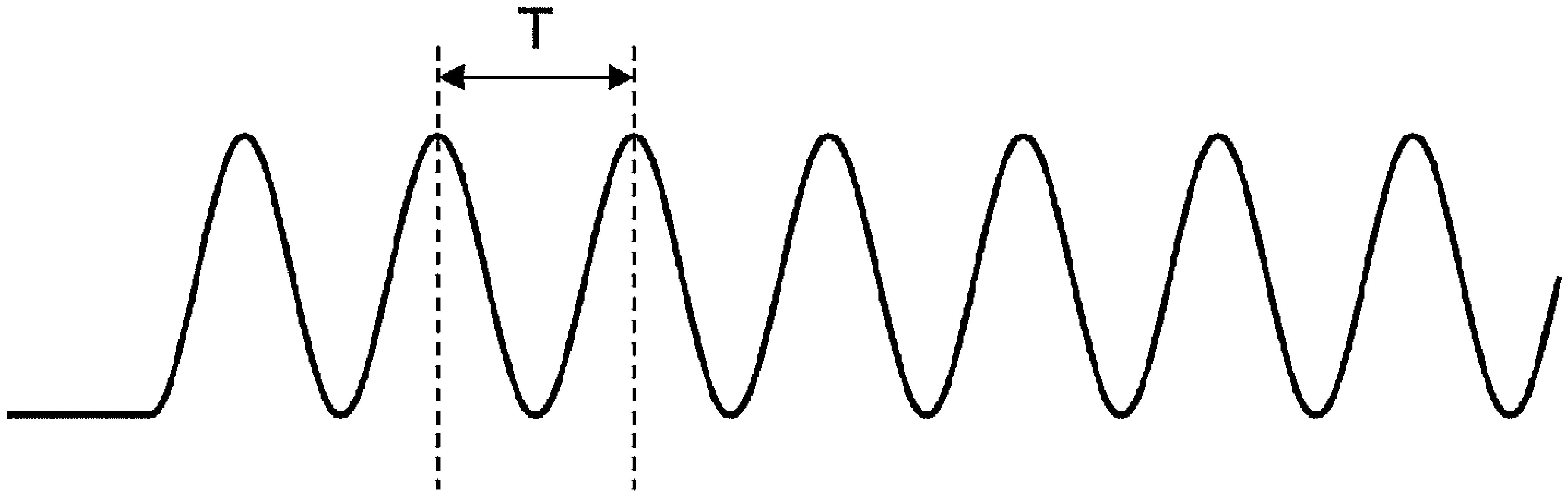


FIG.9B

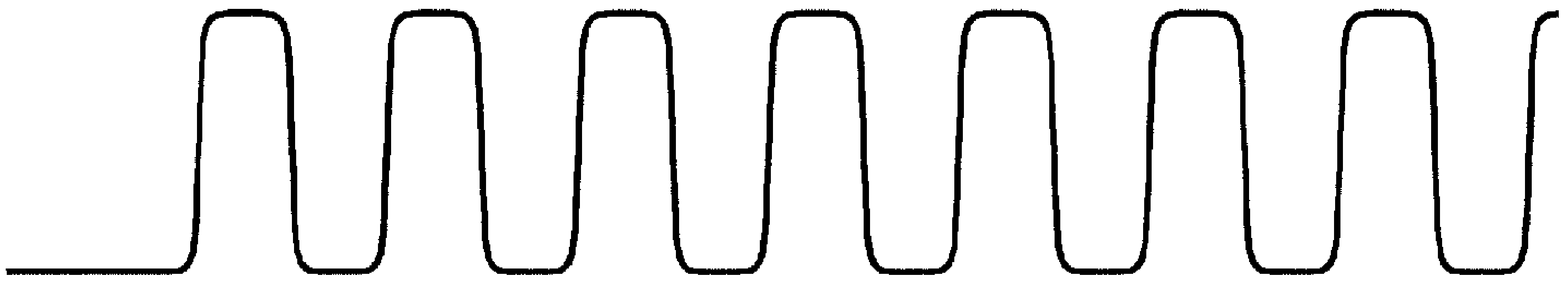


FIG.10

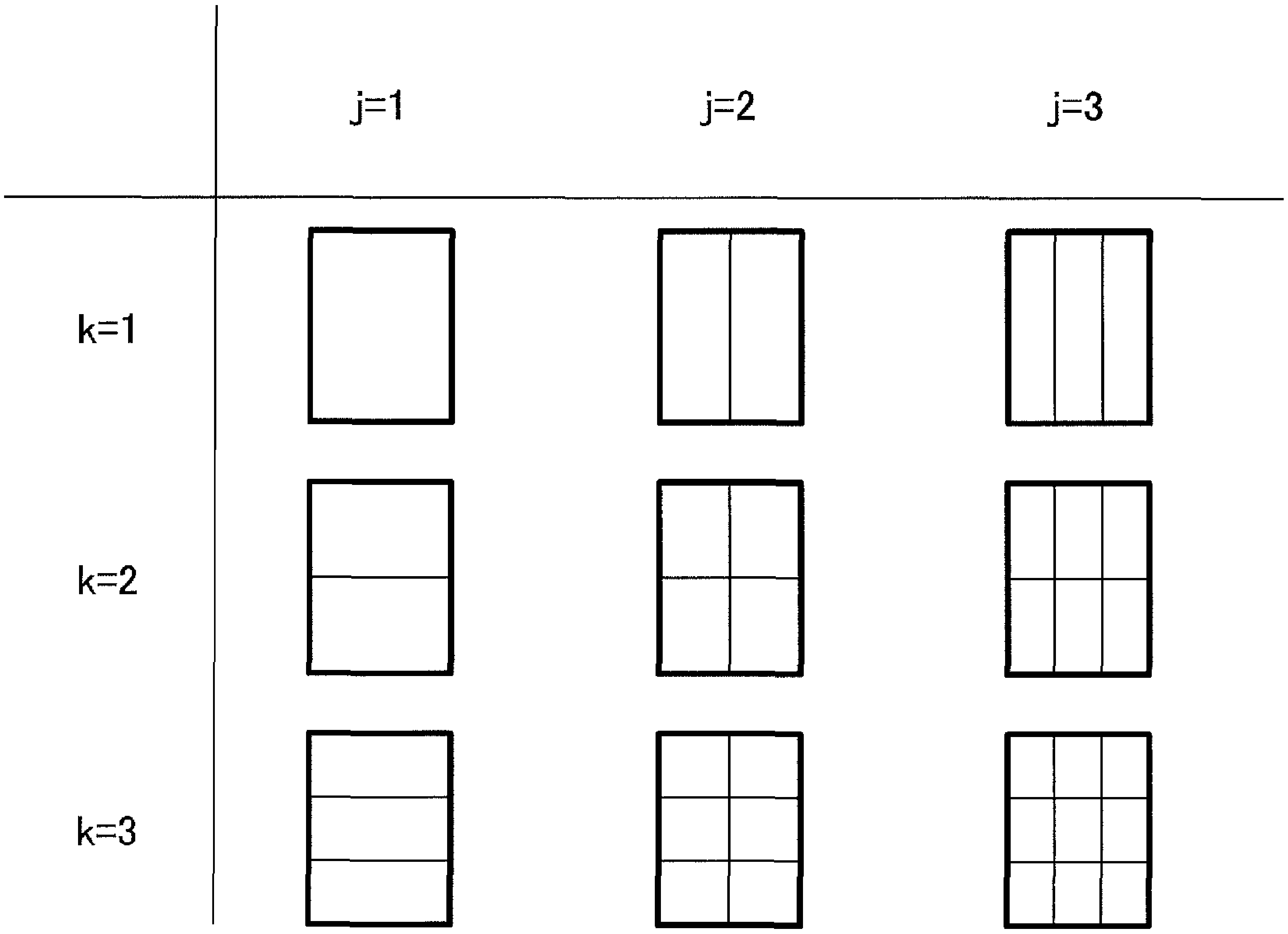


FIG.11

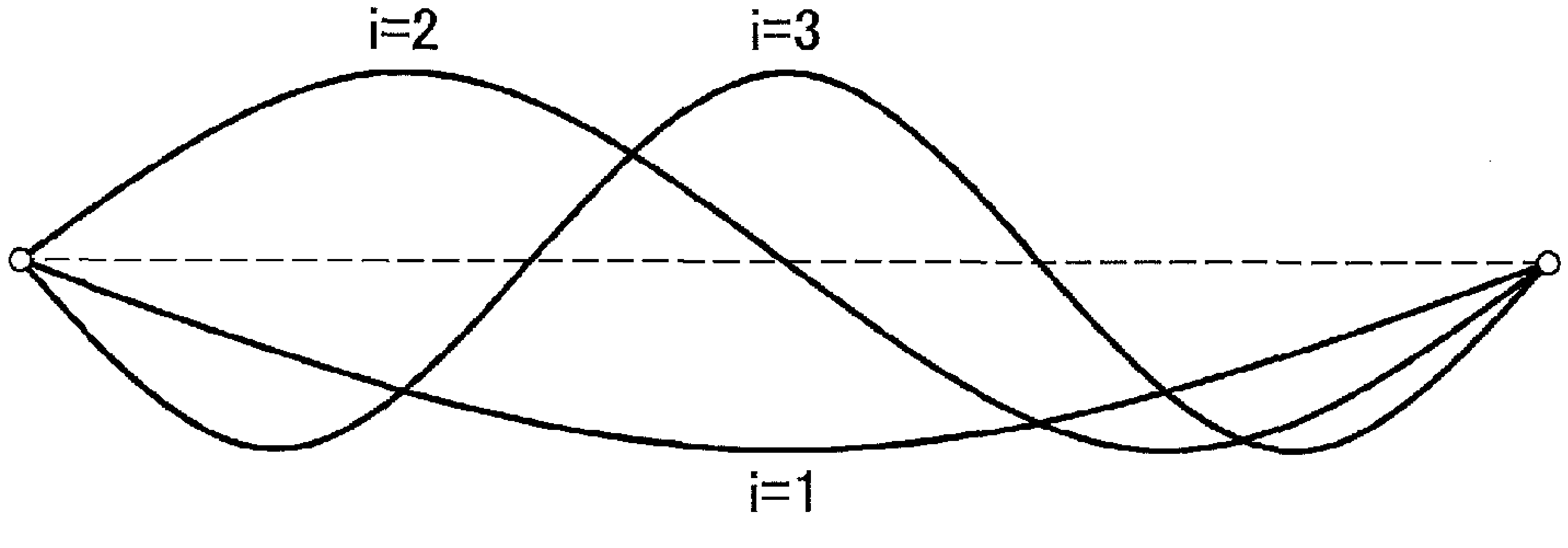


FIG.12

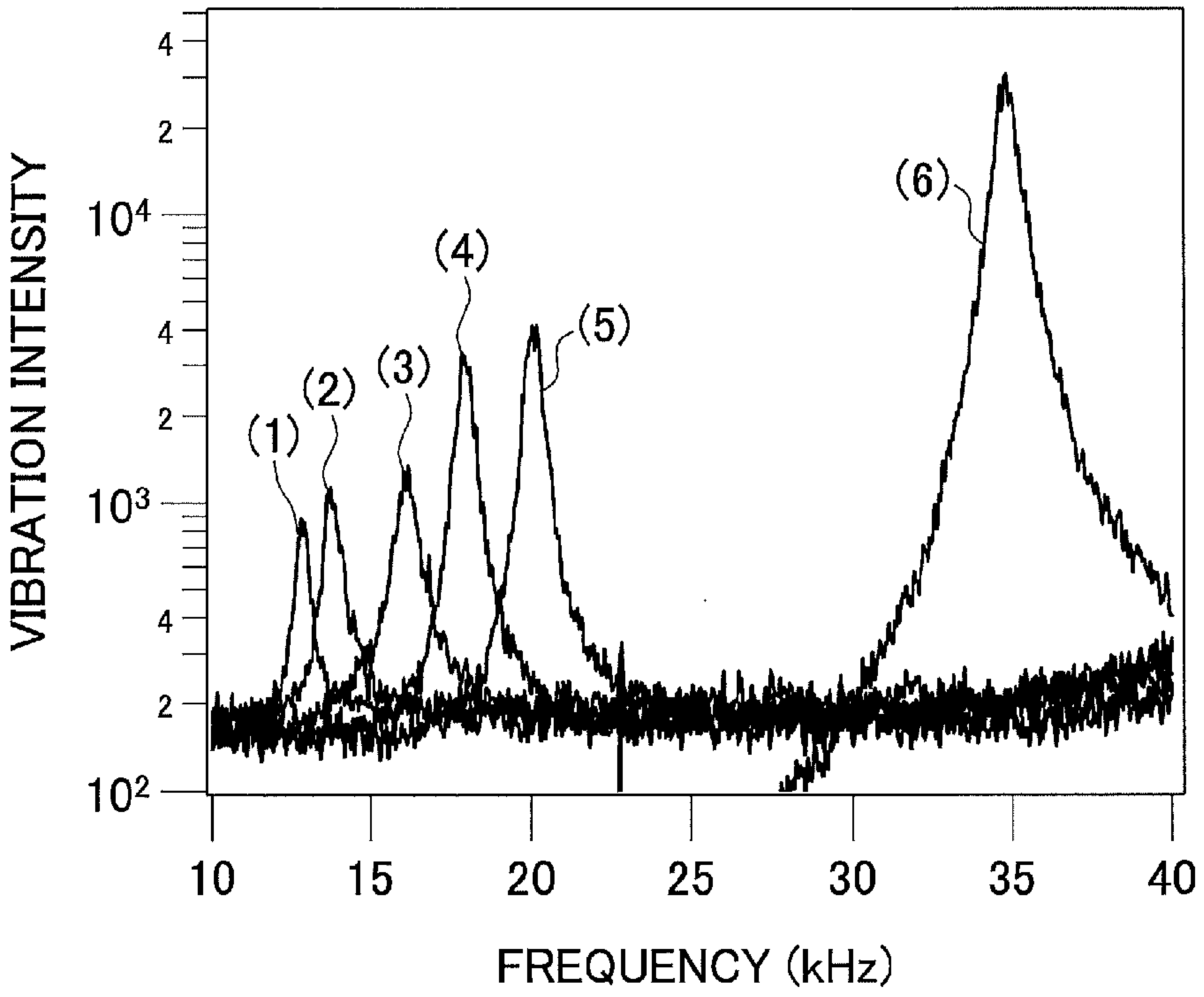

VIBRATION INTENSITY
10^2
2
4
10^3
2
4
10^4
2
4
(1)
(2)
(3)
(4)
(5)
(6)
10
15
20
25
30
35
40
FREQUENCY (kHz)

FIG.13

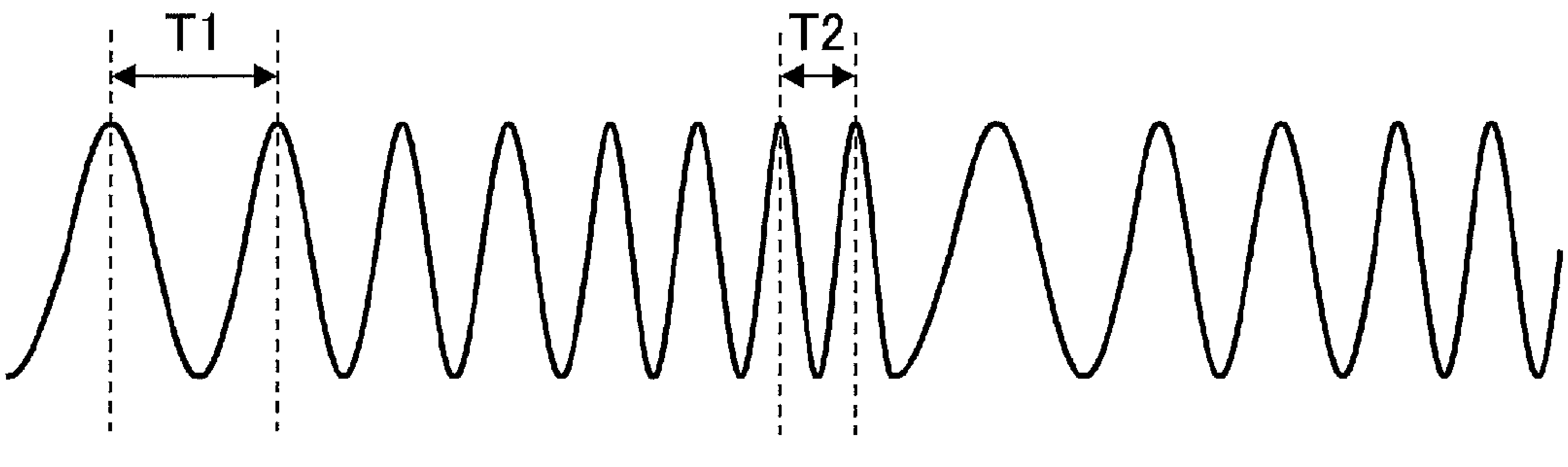

T1
T2

FIG.14

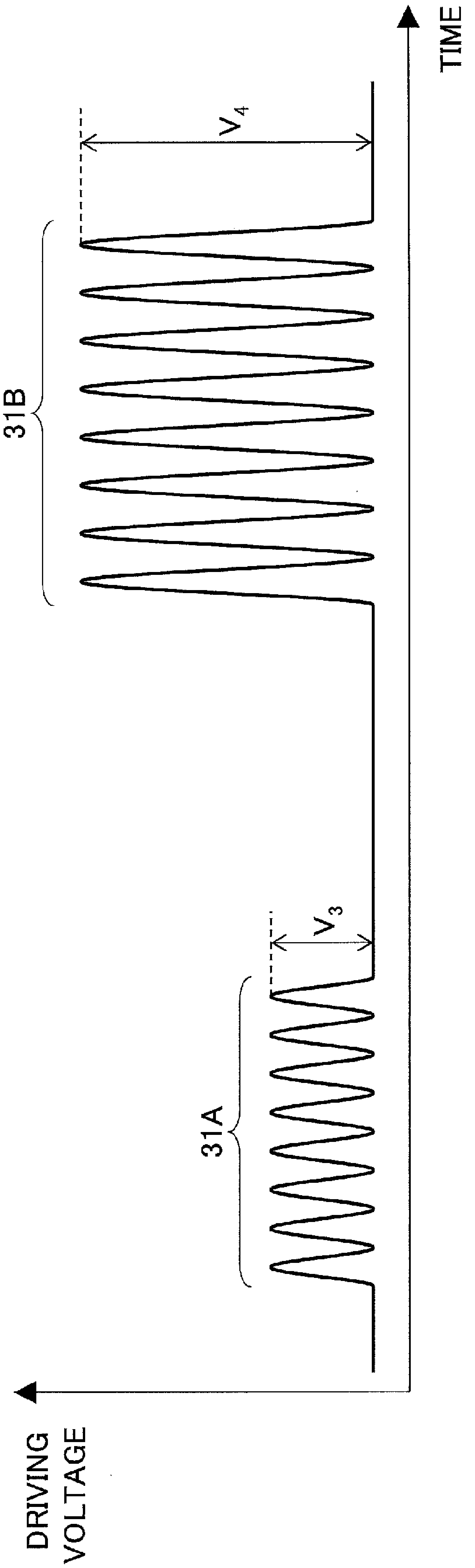


FIG.15A

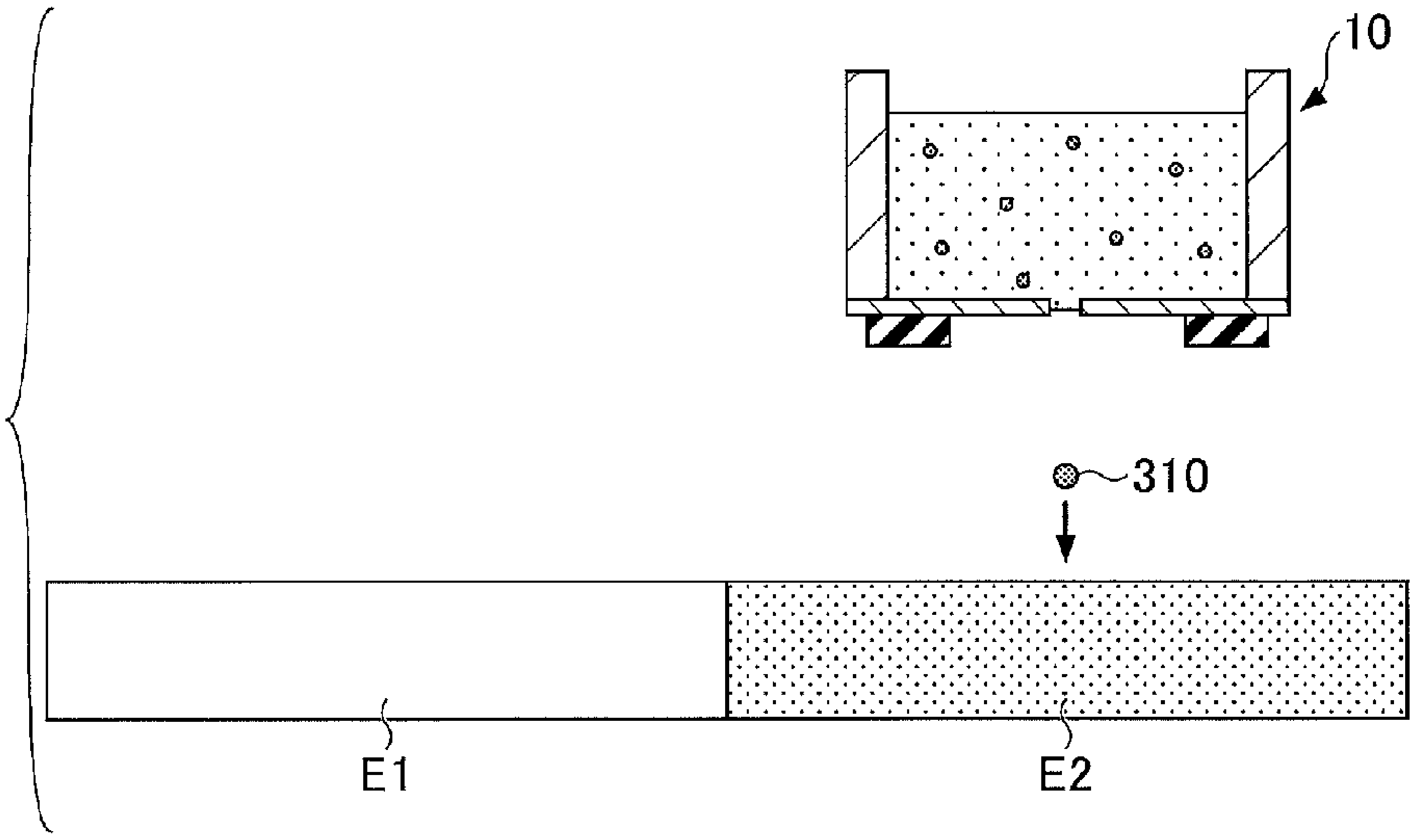


FIG.15B

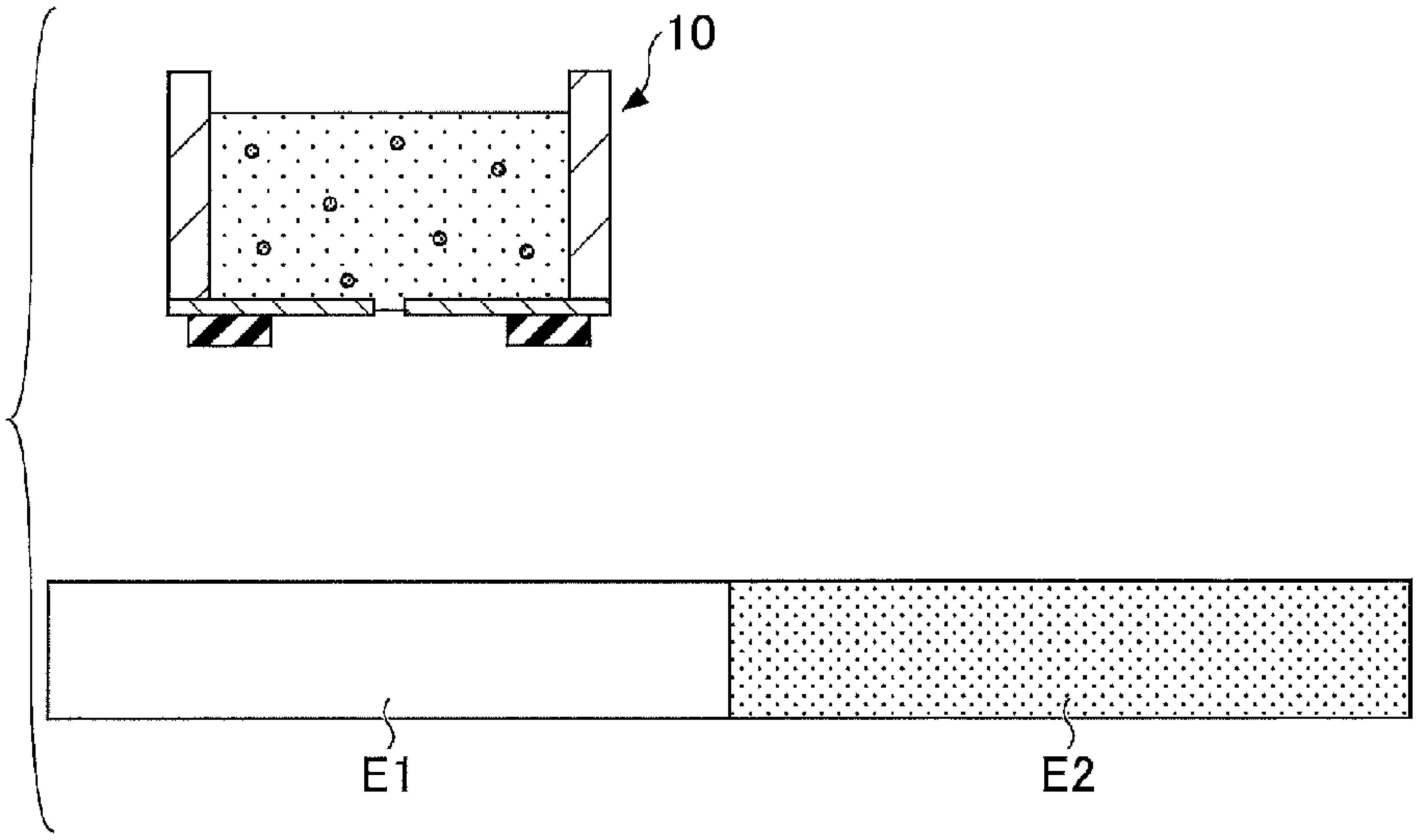


FIG.16

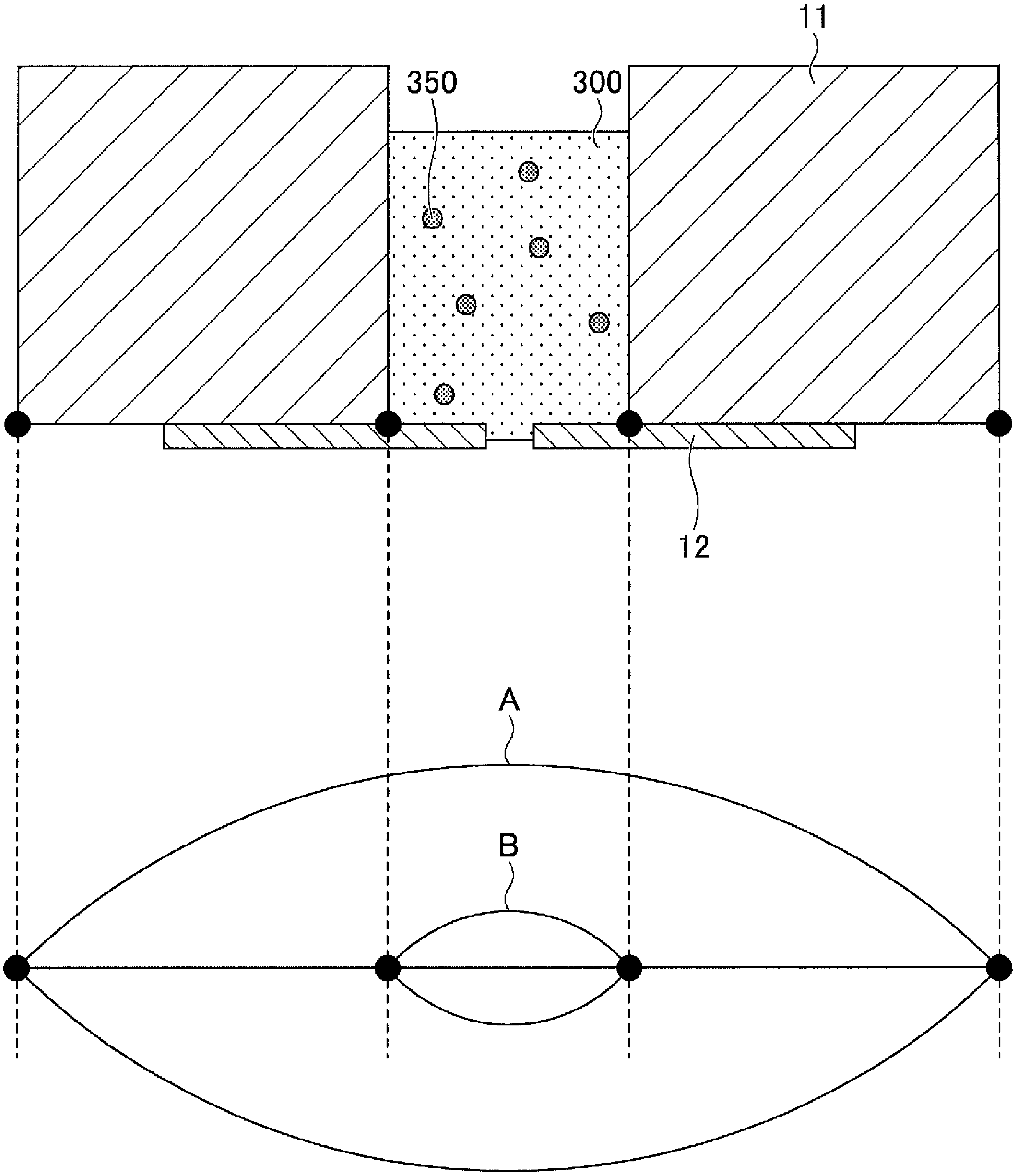


FIG.17A

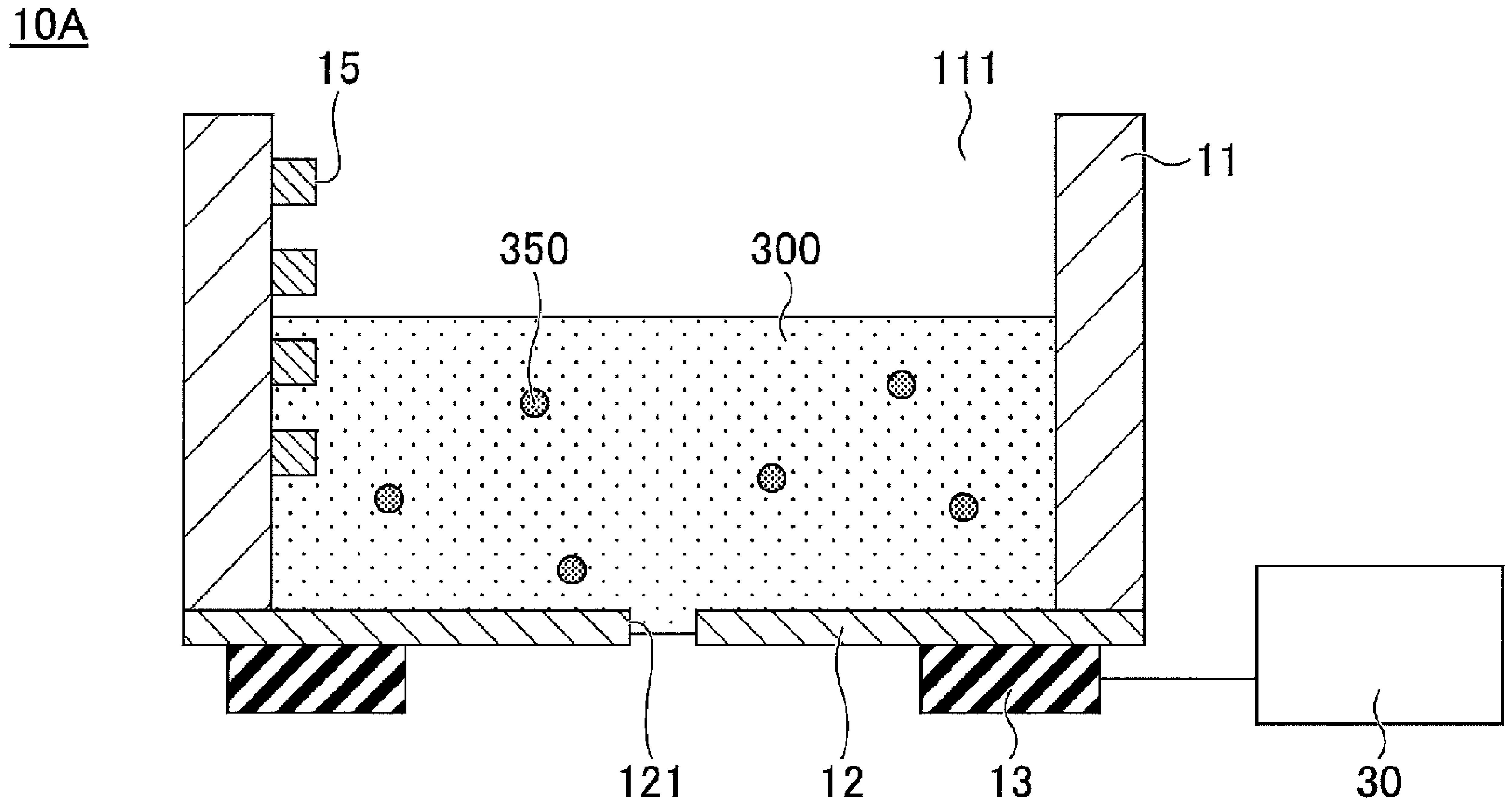


FIG.17B

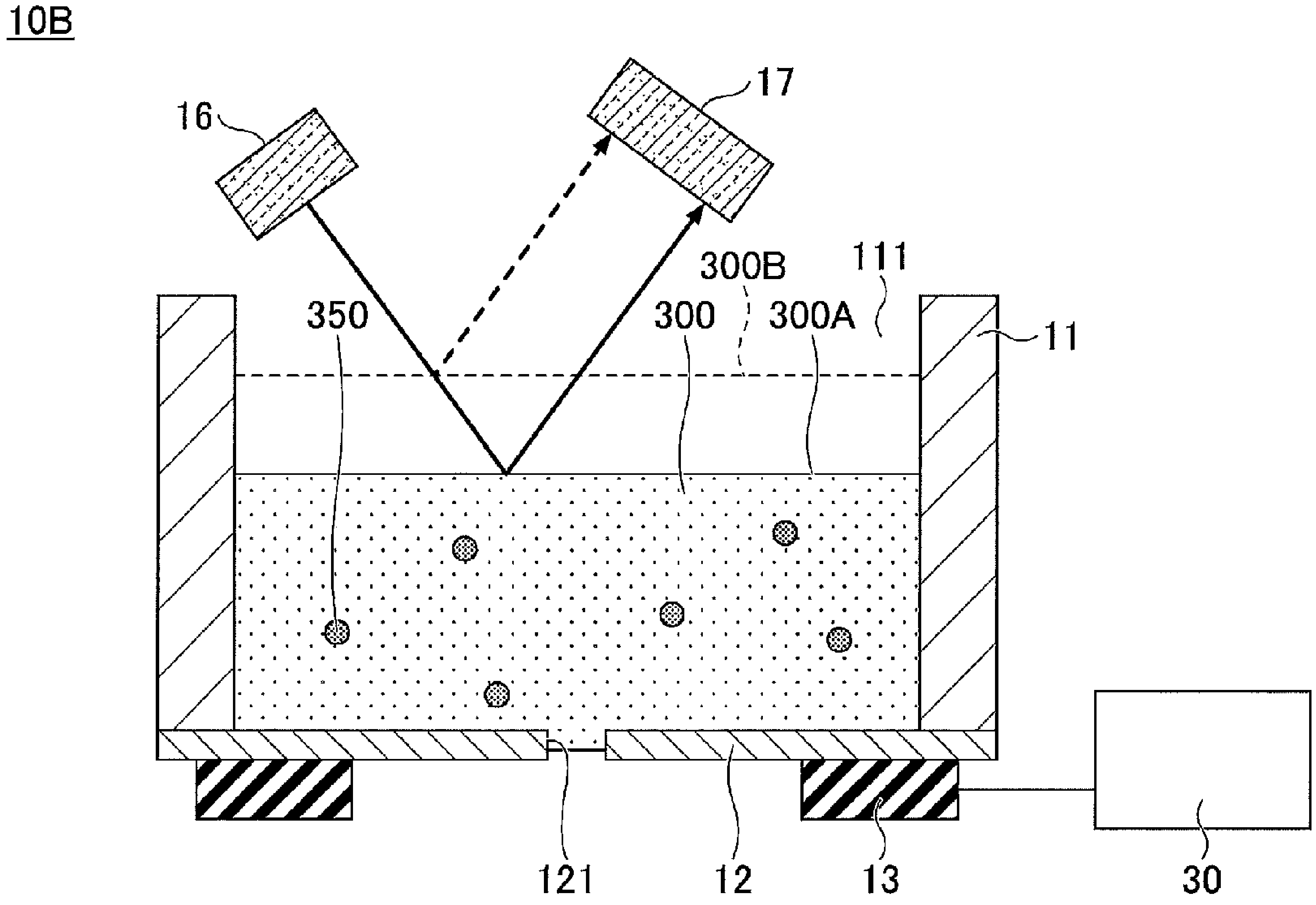


FIG.18

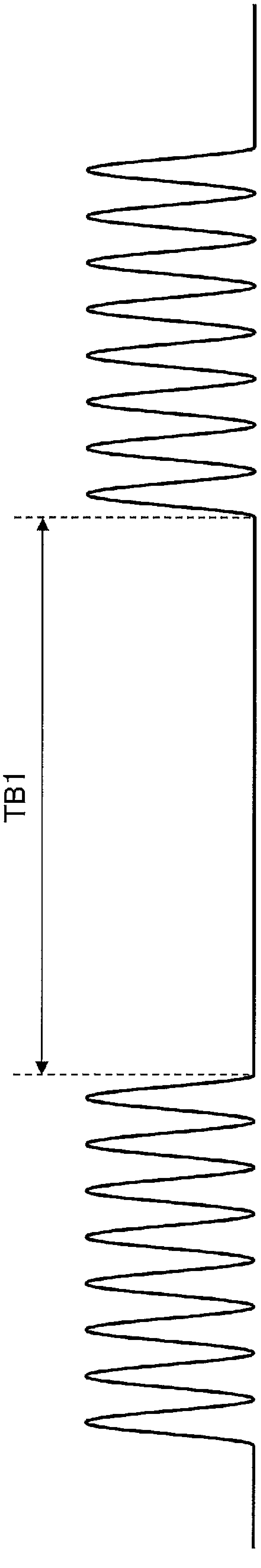


FIG.19

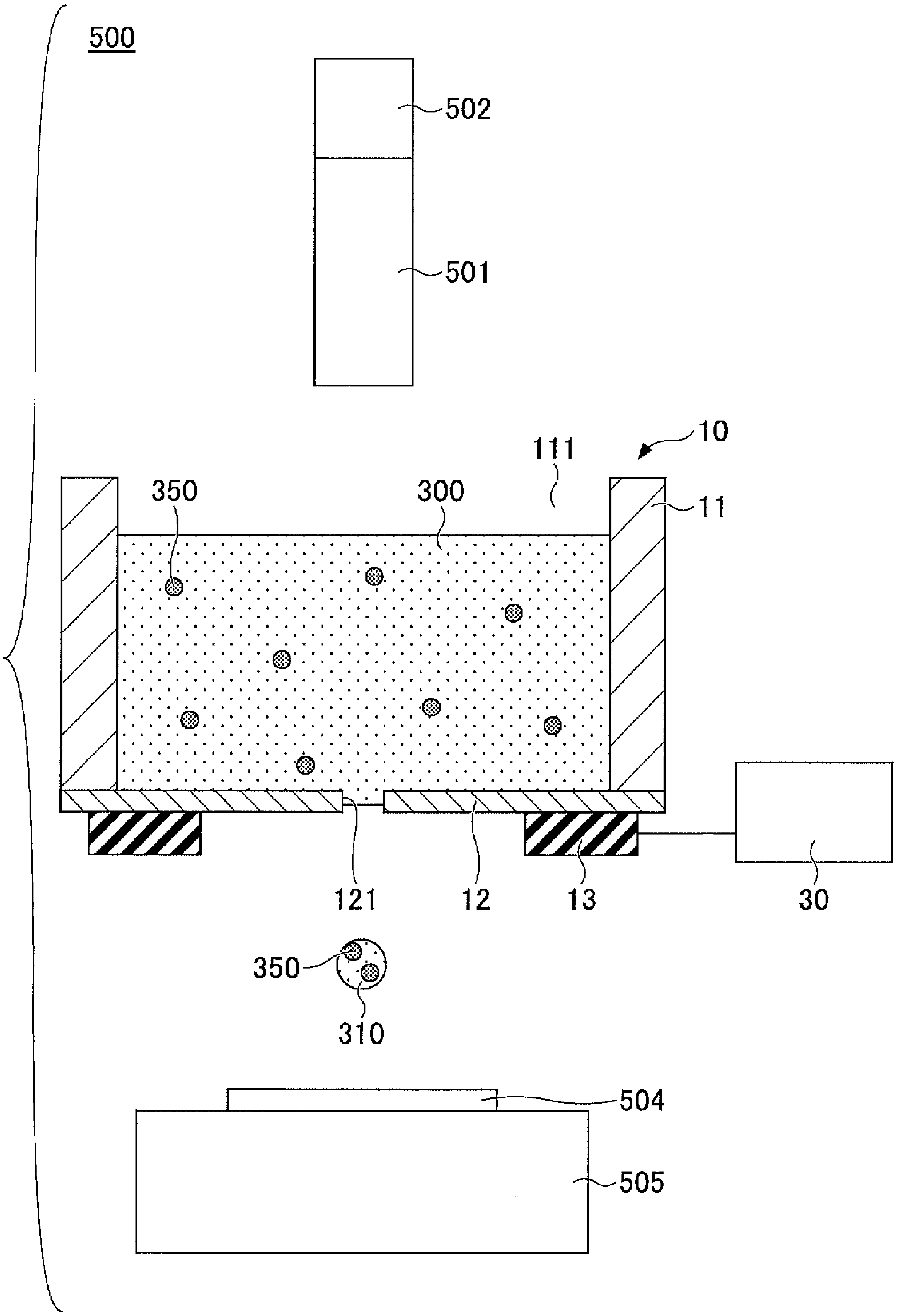


FIG.20A

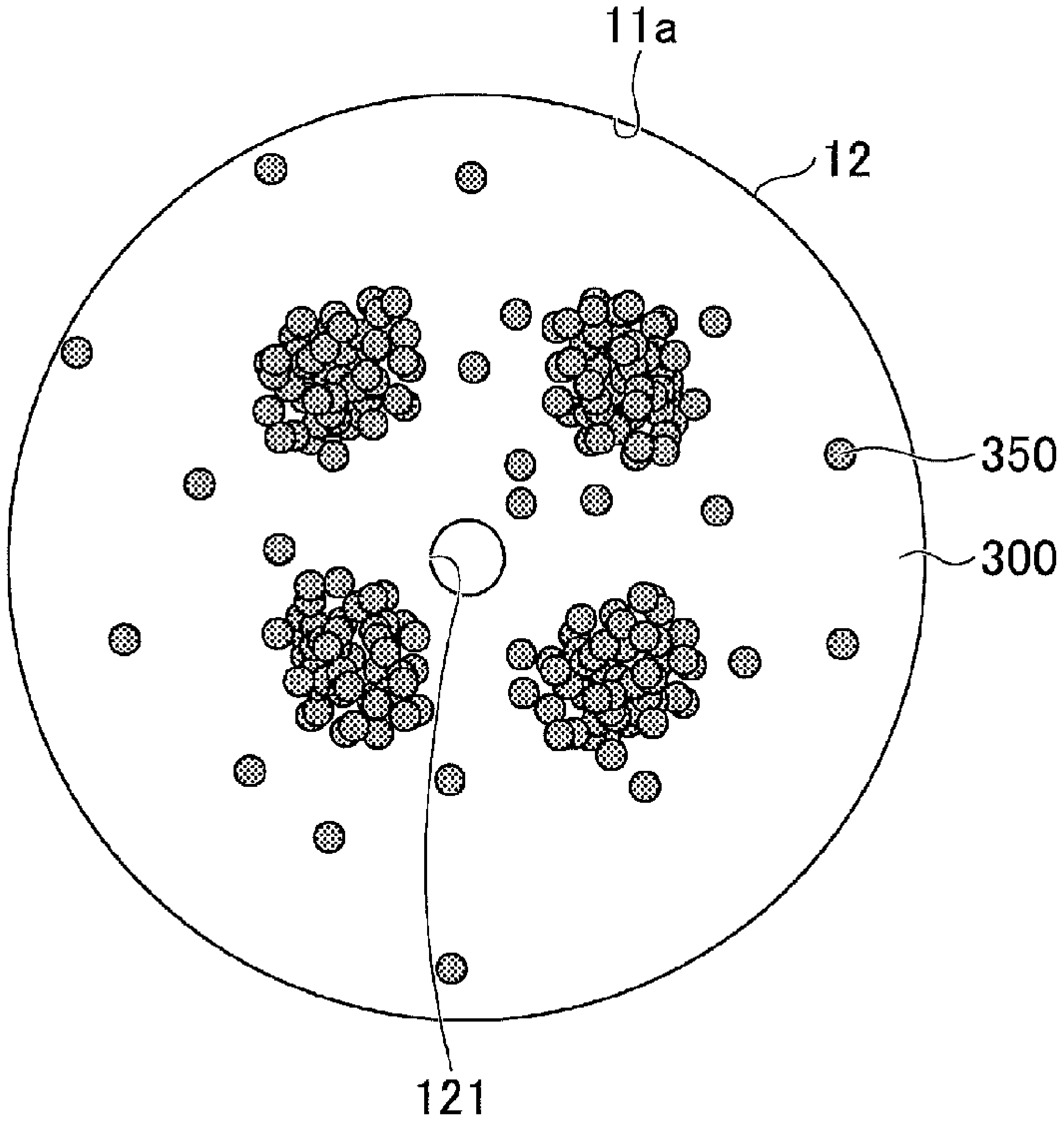


FIG.20B

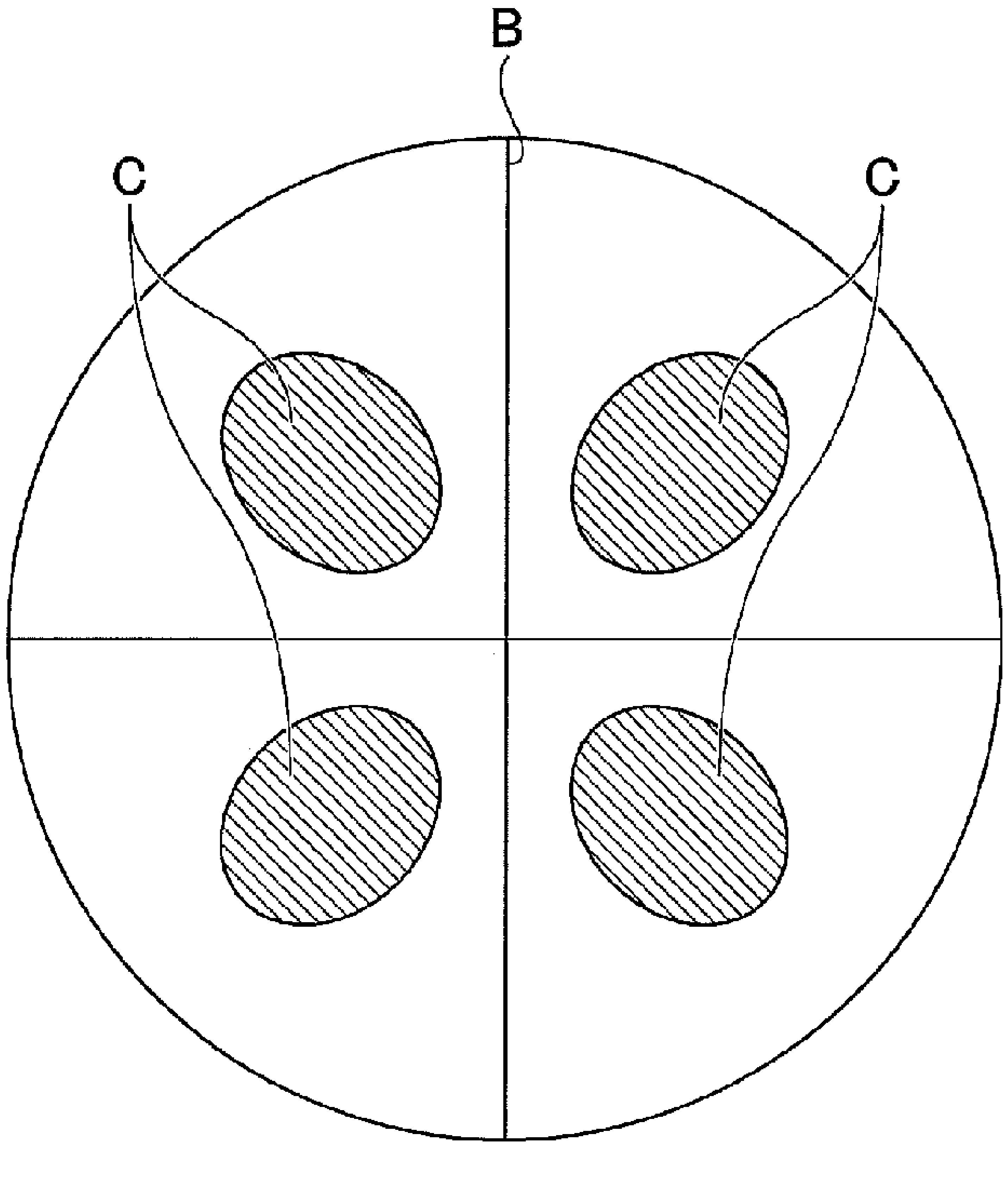
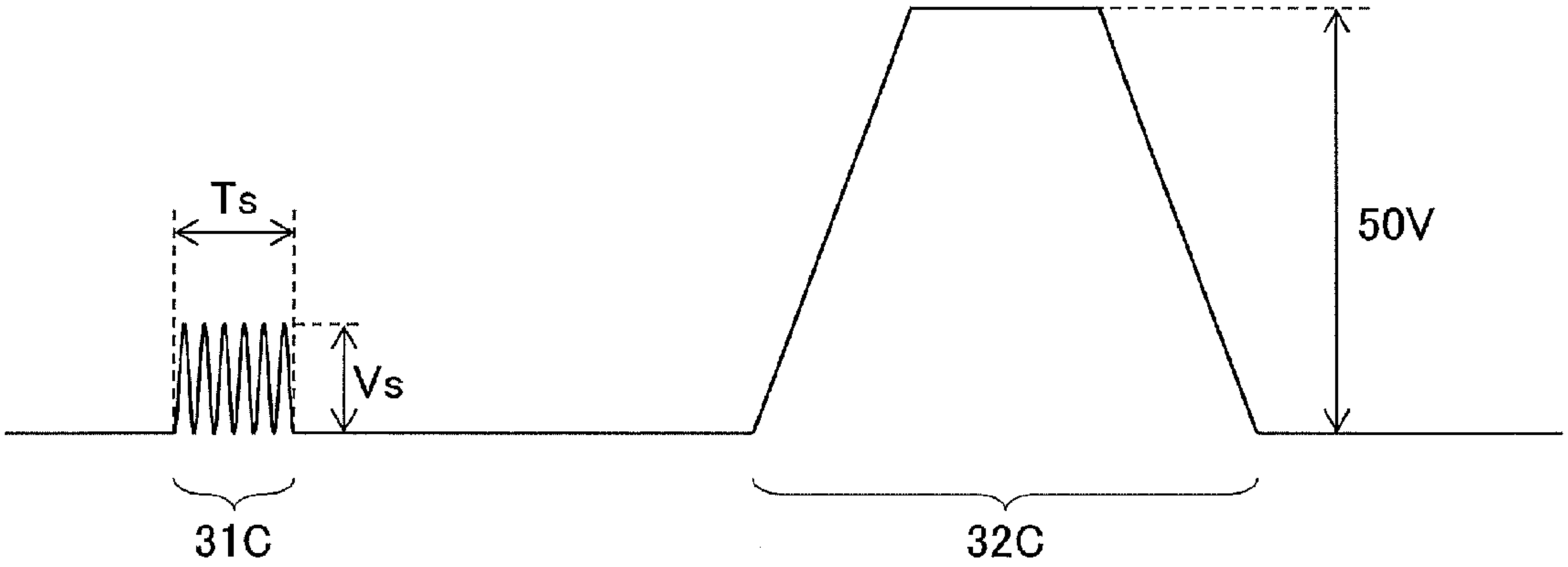


FIG.21



LIQUID DROPLET FORMING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present disclosure relates to liquid droplet forming apparatuses.

2. Description of the Related Art

Conventionally, a liquid droplet forming apparatus that ejects liquid held in a liquid chamber as a droplet is known in the art. In the conventional liquid droplet forming apparatus, for example, dispersing liquid using a pigment as colorant is used as the liquid to be ejected.

However, in the dispersing liquid using a pigment as colorant, although the pigment does not precipitate by itself, the pigment may precipitate due to congelation caused by Van der Waals' forces, etc., when the dispersing liquid using a pigment as colorant is left in the liquid droplet forming apparatus for a long time. When coagula of the pigment precipitate, the liquid cannot be stably ejected due to a clogging nozzle. Therefore, the liquid needs to be dispersed again so as to prevent the coagulation of the pigment (for example, see Patent document 1).

Recently, a technology in which a plurality of cells are ejected using inkjet is developed as stem cell technology advances. A cell is a precipitating particle that precipitates upon being left for long time. Although conventional particles (such as the pigment) ejected by the conventional liquid droplet forming apparatus precipitate after being coagulated, the precipitating particle such as a cell may solely precipitates without being coagulated since the precipitating particle is heavier than a conventional particle having a diameter 100 times greater than a diameter of the conventional particle.

Therefore, when using a method for the conventional liquid droplet forming apparatus, it is difficult to sufficiently stir liquid including the precipitating particles, and variance in a number of the precipitating particles included in an ejected droplet may be caused due to the precipitation of the precipitating particles.

RELATED ART DOCUMENT

Patent Document

[Patent Document 1]: Japanese Unexamined Patent Application Publication No. H06-087220

SUMMARY OF THE INVENTION

An object of disclosure of the present technology is to provide a liquid droplet forming apparatus capable of reducing variance in a number of the precipitating particles included in an ejected droplet.

The following configuration is adopted to achieve the aforementioned object.

In one aspect of the embodiment, there is provided a liquid droplet forming apparatus comprising: a liquid holding part configured to hold a liquid including precipitating particles; a film member configured to be vibrated so as to eject the liquid held in the liquid holding unit, wherein a nozzle is formed in the film member and the liquid is ejected as a droplet from the nozzle; a vibrating unit configured to vibrate the film member; and a driving unit configured to selectively apply an ejection waveform and a stirring waveform to the vibrating unit, wherein the film member is vibrated to form the droplet in response to applying the ejection waveform and the film member is vibrated without forming the droplet in response to applying the stirring waveform.

Other objects, features and advantages of the present invention will become more apparent from the following detailed description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross sectional view of a liquid droplet forming apparatus of the first embodiment.

FIG. **2** is a diagram for illustrating biased accumulation of particles.

FIG. **3**A is a diagram for illustrating example method for reducing biased accumulation of the precipitating particles.

FIG. **3**B is another diagram for illustrating example method for reducing biased accumulation of the precipitating particles.

FIG. **4**A is a diagram for schematically illustrating liquid including precipitating particles held and left in the liquid chamber.

FIG. **4**B is a diagram for schematically illustrating the precipitating particles stirred due to vibration of a membrane, where a driving device inputs the stirring waveform so as to have the membrane vibrate without forming the droplets.

FIG. **4**C is a diagram for schematically illustrating a droplet formed by the vibration of the membrane, where the driving device inputs the ejection waveform.

FIG. **5**A is a diagram for illustrating difference between the liquid droplet forming apparatus **10** and a conventional liquid droplet forming apparatus.

FIG. **5**B is another diagram for illustrating difference between the liquid droplet forming apparatus **10** and the conventional liquid droplet forming apparatus.

FIG. **6** is another diagram for illustrating difference between the liquid droplet forming apparatus **10** and the conventional liquid droplet forming apparatus.

FIG. **7** is a diagram for illustrating examples of the stirring waveform and the ejection waveform generated by the driving device.

FIG. **8** is a diagram for illustrating natural vibration modes of a disk whose edge is fixed.

FIG. **9**A is a diagram for illustrating a sine wave including only a specific frequency component.

FIG. **9**B is diagram for illustrating a waveform generated by performing low-pass filtering on rectangular wave.

FIG. **10** is a diagram for illustrating the natural vibration modes of a rectangular plate whose edge is fixed.

FIG. **11** is a diagram for illustrating the natural vibration modes of a slit plate fixed at both edges thereof.

FIG. **12** is a graph for illustrating an example measuring result of the natural frequency of the basic mode in a prototype liquid droplet forming apparatus.

FIG. **13** is a diagram for schematically illustrating an example stirring waveform whose frequency varies in a range from a first frequency to a second frequency.

FIG. **14** is a diagram for illustrating an example stirring waveforms with discrete driving voltages.

FIG. **15**A is a diagram for illustrating drawing regions in a case where the stirring is performed by using the stirring waveforms shown in FIG. **14**.

FIG. **15**B is another diagram for illustrating drawing regions in a case where the stirring is performed by using the stirring waveforms shown in FIG. **14**.

FIG. **16** is a diagram for illustrating a method for vibrating a member greater than a membrane.

FIG. **17**A is a diagram for illustrating a cross sectional view of the liquid droplet forming apparatus of a third variation of the first embodiment.

FIG. **17**B is another diagram for illustrating a cross sectional view of the liquid droplet forming apparatus of a third variation of the first embodiment.

FIG. **18** is a diagram for illustrating an example of appropriate stirring waveform generated by a driving device.

FIG. **19** is a diagram for illustrating an observation apparatus.

FIG. **20**A is a diagram for illustrating biased dispersion of the particles.

FIG. **20**B is another diagram for illustrating biased dispersion of the particles.

FIG. **21** is a diagram for illustrating a stirring waveform and an ejection waveform.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Herein below, embodiments will be described with reference to the accompanying drawings. Additionally, in respective embodiments (or variations), identical reference numerals will be applied to an elements or the like that have substantially similar functions and configurations to those in another embodiment (or a variation of the embodiment), and descriptions thereof may be omitted.

First Embodiment

Structure of Liquid Droplet Forming Apparatus

In the following, a first embodiment will be described. FIG. **1** is a cross sectional view of a liquid droplet forming apparatus of the first embodiment. With reference to FIG. **1**, the liquid droplet forming apparatus **10** includes a liquid chamber **11**, a membrane **12**, a piezoelectric element **13** and a driving device **30**. FIG. **1** schematically illustrates the liquid chamber **11** holding liquid (liquid solution) **300** including precipitating particles **350**.

Additionally, in the present embodiment, the liquid chamber **11** side is referred to as the upper side, while the piezoelectric elements **13** side is referred to as the lower side. Also, the liquid chamber **11** side in respective portions (parts) is referred to as the upper side of the portion (part) while the piezoelectric elements **13** side in respective portions (parts) is referred to as the lower side of the portion (part). Also, a plan vision means viewing an object from the upper side of the membrane **12** in normal line direction, and a planar shape means a shape of an object viewing from the upper side of the membrane **12** in normal line direction.

In the liquid droplet forming apparatus **10**, the liquid chamber **11** is a liquid holding unit for holding the liquid **300** including the precipitating particles **350** (precipitating particles **350** being dispersed), and the liquid chamber **11** can be made of metal, silicon, ceramic, and the like. The liquid chamber **11** includes an atmosphere opening part **111** for opening the inside of the liquid chamber **11** to the atmosphere, where the atmosphere opening **111** is formed in upper side of the liquid chamber **11** so that the bubbles mixed with the liquid **300** can be ejected from the atmosphere opening **111**.

The membrane **12** is a film shape member fixed at the lower end of the liquid chamber **11**. A nozzle **121** that is a through hole is formed in approximate center of the membrane **12**, where the liquid **300** held in the liquid chamber **11** is ejected as a droplet from the nozzle **121** through vibration of the membrane **12**. For example, the planar shape of the membrane **12** may be circular, ellipsoidal, rectangular, and the like.

Magnitude of the vibration is smaller at outer edge portion of the membrane **12**, which corresponds to a bottom surface of the liquid chamber **11**, in comparison to the magnitude of the vibration at center portion of the membrane **12** since the outer edge portion of the membrane **12** is fixed at the lower end of the liquid chamber **11**. Therefore, as shown in FIG. **2**, precipitating particles **350** having precipitated are likely to accumulate at the outer edge portion of the membrane **12**, which corresponds to the bottom surface of the liquid chamber **11**. Additionally, upper side in FIG. **2** illustrates a state of the membrane **12** before the vibration while lower side in FIG. **2** illustrates a state of the membrane **12** after the vibration, where an arrow is shown between the upper side and the lower side in FIG. **2**.

FIG. **3**A and FIG. **3**B are diagrams for illustrating example methods for reducing biased accumulation of the precipitating particles. In FIG. **3**A, inside wall shape of lower end portion of the liquid chamber **11** is curved in a cross sectional view. In FIG. **3**B, shape of the outer edge portion of the membrane **12** is curved in the cross sectional view. As shown in FIG. **3**A and FIG. **3**B, when bottom of the liquid chamber **11** has the curved shape in which thickness of the bottom becomes greater as a position in the bottom becomes closer to the outer edge of the bottom, the biased accumulation (tendency to accumulate at the outer edge portion of the bottom surface of the liquid chamber **11**) of the precipitating particles **350** can be reduced.

Materials for forming the membrane **12** are not limited. However, preferably, a material with a certain hardness is used since the membrane **12** formed of a too soft material that too easily vibrates is difficult to stop the vibration when the droplet is not ejected. For example, a metal material, a ceramic material, a polymer material with a certain hardness may be used for forming the membrane **12**. Additionally, in particular, a material with low adhesiveness to the precipitating particle **350** is preferable.

Generally, adhesiveness of a cell is considered to be dependent on a contact angle of the material and water. The adhesiveness of the cell is small when the material has a high hydrophilicity or a high hydrophobicity. Various metal materials or ceramic material (metal oxide) can be used as the material with a high hydrophilicity, while fluorinated resin, etc., can be used as the material with a high hydrophobicity.

Stainless steel, nickel aluminum, silicon dioxide, alumina, zirconia, etc., can be exemplified as the material. Also, the adhesiveness of the cell can be reduced by coating a surface of the material, where the surface of the material can be coated with the aforementioned metal material, metal oxide, or synthetic phospholipid polymer (e.g., Lipidure, manufactured by NOF Corporation).

The nozzle **121** is preferably formed at an approximate center of the membrane **12** as a through hole whose shape is substantially true circular. A diameter of the nozzle **121** is not limited. However, the diameter is preferably more than twice of size of the precipitating particle **350** in order to avoid the nozzle **121** being clogged with the precipitating particles **350**.

The piezoelectric element **13** is formed at the lower surface of the membrane **12**. A shape of the piezoelectric element **13** may be designed in accordance with the shape of the membrane **12**. For example, when the planar shape of the membrane **12** is circular, preferably, the piezoelectric element **13** is annularly (in ring-shape) formed around the nozzle **121**.

For example, the piezoelectric element **13** has a structure in which a voltage is applied to an upper surface and a lower surface of piezoelectric material. When the voltage is applied to upper and lower electrodes of the piezoelectric element **13**, compression stress is applied in a horizontal direction of the paper, thereby having the membrane **12** vibrate. For example, lead titanate zirconate can be used as the piezoelectric material. Also, materials of bismuth iron oxide, niobium oxide metal, barium titanate, a material created by adding metal or another oxide to the aforementioned materials, etc., may be used as the piezoelectric material.

However, a vibrator (vibrating unit) for vibrating the membrane **12** is not limited to the piezoelectric element **13**. For example, the membrane **12** can vibrate due to a difference of linear expansion coefficients when a material having a linear expansion coefficient different from the linear expansion coefficient of the membrane **12** is pasted on the membrane **12** and heated. In this case, preferably, a heater is formed in the material having the different linear expansion coefficient, where the material is heated through power supply to the heater so as to vibrate the membrane **12**.

The driving device **30** is provided for driving the piezoelectric element **13**. The driving device **30** selectively (e.g., alternately) apply ejection waveform and stirring waveform to the piezoelectric element **13**, where the ejection waveform is applied to have the membrane **12** vibrate to form the droplet and the stirring waveform is applied to have the membrane **12** vibrate without forming the droplet.

That is, the driving device **30** applies the ejection waveform to the piezoelectric element **13** to control the vibration of the membrane **12**, thereby ejecting the liquid **300** held in the liquid chamber **11** as the droplets from the nozzle **121**. Also, the driving device **30** applies the stirring waveform to the piezoelectric element **13** to control the vibration of the membrane **12**, thereby stirring the liquid **300** held in the liquid chamber **11**. Additionally, the droplets are not ejected from the nozzle **121** in the stirring.

As described above, by stirring the liquid **300** during a period in which the droplet is not formed, precipitation and coagulation of the precipitating particles **350** on the membrane **12** during the period in which the droplet is not formed can be prevented. Consequently, clogging of the nozzle **121** and variance of a number of the precipitating particles **350** in an ejected droplet can be reduced.

In the liquid **300** including the precipitating particles **350**, the precipitating particles **350** may be metal fine particles, inorganic fine particles, cell (in particular, human-derived cell), and the like. Although, types of metal fine particles are not limited, silver particles, cupper particles, etc., may be used for drawing wiring with the ejected droplets.

Although, types of the inorganic fine particles are not limited, titanium oxide, silicon dioxide, etc., may be used as white ink, for coating spacer materials, and the like. As for type of the cells, animal cells (in particular, human-derived cells) are preferably used. In this case, the liquid droplet forming apparatus **10** is used as an apparatus for ejecting cells so as to form tissue fragment used in evaluating medical benefit or cosmetics.

Generally, solvent of the liquid **300** is water. However, this is not a limiting example, and various organic solvents such as alcohol, mineral oil, and vegetable oil may be used. When the water is used as the solvent, preferably, wetting agent for reducing vaporization of the water, or surface active agent for reducing surface tension is included. Materials generally used in inkjet inks can be used for formulating the aforementioned agents.

Although, amount of the liquid **300** held in the liquid chamber **11** is not limited, typically, 1 μl to 1 ml of the liquid **300** is held. Preferably, 1 μl to 50 μl of the liquid **300** is held since the droplets can be formed with small amount of the liquid **300** in a case where an expensive liquid such as a cell suspension liquid is used.

<Droplet Forming Process of Liquid Droplet Forming Apparatus>

In the following, a droplet forming process by the liquid droplet forming apparatus of the first embodiment will be described. FIG. **4**A, FIG. **4**B and FIG. **4**C are diagrams for illustrating the droplet forming process. FIG. **4**A is a diagram for schematically illustrating the liquid **300** including the precipitating particles **350** held and left in the liquid chamber **11**. At a stage shown in FIG. **4**A, the precipitating particles **350** are precipitated in the bottom of the liquid chamber **11**.

When a droplet forming operation is performed in a state shown in FIG. **4**A, the droplet may not be formed since the precipitating particles **350** are congregated around the nozzle **121**. Also, when a droplet forming operation is performed in a state shown in FIG. **4**A, a great amount of the precipitating particles **350** may be ejected at once and then supernatant of the liquid **300** may be ejected. Therefore, the number of the precipitating particles **350** in the droplet may significantly vary even if the droplets can be formed.

FIG. **4**B is a diagram for schematically illustrating the precipitating particles **350** stirred due to the vibration of the membrane **12**, where the driving device **30** inputs the stirring waveform into the piezoelectric element **13** so as to have the membrane **12** vibrate without forming the droplets. The liquid surface around the nozzle **121** vibrates significantly due to the vibration of the membrane **12**, which causes convective flows shown as arrows "A" in FIG. **4**B to stir the liquid **300** including the precipitating particles **350**.

FIG. **4**C is a diagram for schematically illustrating the droplet **310** formed by the vibration of the membrane **12**, where the driving device **30** inputs the ejection waveform into the piezoelectric element **13**. When the driving device **30** applies the ejection waveform to the piezoelectric element **13** as shown in FIG. **4**C after the precipitating particles **350** are dispersed in the liquid chamber **11** as shown in FIG. **4**B, the droplets **310** can be formed in a manner where the numbers of the precipitating particles **350** in the respective droplets **310** are kept uniform.

The liquid droplet forming apparatus **10** can stir the precipitating particles **350** more efficiently in comparison to a conventional liquid droplet forming apparatus. This will be described in detail with reference to FIG. **5**A, FIG. **5**B and FIG. **6**.

FIG. **5**A and FIG. **5**B are diagrams for illustrating difference between the liquid droplet forming apparatus **10** and the conventional liquid droplet forming apparatus. FIG. **6** is another diagram for illustrating difference between the liquid droplet forming apparatus **10** and the conventional liquid droplet forming apparatus.

In a conventional liquid droplet forming apparatus **600** shown in FIG. **5**A, a piezoelectric element **630** is disposed in an upper side or in a side surface of a liquid chamber **610**. In the liquid droplet forming apparatus **600**, the piezoelectric element **630** is vibrated as shown as solid arrows to give motion energy to the precipitating particles **650** through dispersing liquid held in the liquid chamber **610**, thereby dispersing the precipitating particles **650** that are precipitated and congregated around the nozzle **621** or flow passage **620** as shown as dotted arrows.

In this case, as shown in FIG. **6**, each precipitating particle **650** slightly vibrates. Hence, the respective precipitating particles **650** vibrate at respective positions in the entire liquid chamber **610**. Therefore, although the precipitated and congregated precipitating particles **650** can be dispersed, the precipitating particles **650** cannot be stirred.

That is, when using a method in which the motion energy is given to the precipitating particles **650** through dispersing liquid as performed in the liquid droplet forming apparatus **600**, the precipitating particles **650** cannot be stirred enough to be uniform in the liquid chamber and the precipitating particles **650** exist in the liquid chamber **610** with a certain distribution. Therefore, the number of the precipitating particles **650** in the ejected droplet may vary.

On the other hand, in the liquid droplet forming apparatus **10** shown in FIG. **5**B, the piezoelectric element **13** is disposed at lower side of the membrane **12** in which the nozzle **121** is formed. Therefore, the membrane **12** vibrates as shown as solid arrows in accordance with the vibration of the piezoelectric element **13** as shown as solid arrows, thereby causing a liquid flow from lower side to upper side of the liquid chamber **11**.

In this case, as shown in FIG. **6**, each precipitating particle **350** moves from the lower side to the upper side. Hence, convective flows shown as arrows "A" occurs in entire liquid held in the liquid chamber **11** to stir the liquid **300** including the precipitating particles **350**. That is, according to the liquid flow from the lower side to the upper side of the liquid chamber **11**, the precipitating particles **350** are dispersed to uniformly exist in the liquid chamber **11**, thereby suppressing the variance of numbers of cells in the ejected droplets.

Also, by vibrating the membrane **12** disposed at a lower side of the liquid droplet forming apparatus **10**, the precipitating particles **350** can be efficiently stirred since the motion energy can be directly given to the precipitating particles **350** precipitated in the liquid chamber **11** without involving the dispersing liquid.

Additionally, frequencies for vibrating the piezoelectric element are significantly different in between the liquid droplet forming apparatus **600** and the liquid droplet forming apparatus **10**. In the liquid droplet forming apparatus **600**, the vibration frequency of the piezoelectric element **630** is approximate 100 kHz.

On the other hand, in the liquid droplet forming apparatus **10**, the vibration frequency of the piezoelectric element **13** for stirring the liquid **300** is approximate 20 kHz. The precipitating particles **350** need to be moved slowly and largely since the precipitating particle **350** (e.g., cell) is heavier than the precipitating particle **650** (e.g., pigment) and has a diameter approximate 100 times greater than a diameter of the precipitating particle **650**. Therefore, the frequency in the precipitating particle **10** is lower than the frequency of the liquid droplet forming apparatus **600**.

FIG. **7** is a diagram for illustrating examples of the stirring waveform and the ejection waveform generated by the driving device **30**. In FIG. **7**, the stirring waveform **31** and the ejection waveform **32** respectively consist of square wave, and in the example shown in FIG. **7**, the ejection waveform **32** of a pulse is input after inputting the stirring waveform **31** of pulses for a certain period. A driving voltage V1 of the stirring waveform **31** is less than the driving voltage V2 of the ejection waveform **32** so that the droplet **310** is not formed in response to applying the stirring waveform **31**.

As described above, the liquid droplet forming apparatus **10** of the present embodiment controls the vibration of the membrane **12** to perform stirring and ejection. Hence, the variance of the number of the precipitating particles **350** in the formed droplet **310** can be suppressed by dispersing the liquid **300** including the precipitating particles **350** without causing irregularities in the dispersion, while the clogging of the nozzle **121** can be prevented. Consequently, the liquid **300** including the precipitating particles **350** can be continuously and stably ejected for a long time as the droplets **310**.

First Variation of First Embodiment

An appropriate example of the stirring waveform is shown in the first variation of the first embodiment. Descriptions on elements or the like that have substantially similar functions and configurations to those described above may be omitted in the first variation.

It is known that a disk whose edge (circumference part) is fixed has a plurality of natural vibration modes, which is described in detail, for example, in "WATARI ATSUSHI, *KIKAI SHINDO*, MARUZEN, pp 62-65" (hereinafter, referred to as NonPatent Document 1).

According to NonPatent Document 1, a natural frequency "fns" of a disk can be calculated by using a number "n" of diameter direction nodes and a number "s" of circular nodes.

FIG. **8** is a diagram for illustrating the natural vibration modes of a disk whose edge is fixed. FIG. **8** schematically illustrates the natural vibration modes of the disk in a case where the value "n" of the natural frequency "fns" is "0"-"3" and the value "s" of the natural frequency "fns" is "1"-"3". In FIG. **8**, outer circles indicate the disk, and lines in the outer circles indicate the nodes of vibration. Phases of vibrations of adjacent nodes are reverse to each other.

Here, the vibration of the disk in a case where "n"=0 and "s"=1 is referred to as a basic mode, and respective vibrations other than the basic mode are referred to as higher order modes. As shown in FIG. **8**, the disk includes no nodes of vibration only when the disk vibrates in the basic mode. Respective natural frequencies "fns" of the higher order modes are shown in table 1, where the natural frequency "f0" of the basic mode is set to be "1". According to table 1, when the frequency is more than twice of the natural frequency of the basic mode, a secondary natural vibration mode (natural frequency f11) is excited.

TABLE 1

	s = 1	s = 2	s = 3
n = 0	1	3.91	8.73
n = 1	2.09	5.98	11.9
n = 2	3.43	8.69	15.5

When inputting the stirring waveform to perform stirring by vibrating the membrane **12**, amount of the precipitating particles **350** may be biased in a case where the higher order mode is excited to cause a distribution of vibration intensities in the surface of the membrane **12**. In this case, although uniformity of the amount of the precipitating particles **350** can be improved in comparison to a case where the stirring is not performed, the variance in the number of the precipitating particles **350** in the droplet **310** still remains.

For example, when a frequency of the rectangular wave shown in FIG. **7** is close to the natural frequency of the higher order mode, the higher order mode is excited in response to inputting the rectangular wave. Also, even if the frequency of the rectangular wave is less than the natural frequency of the higher order mode, the higher order mode may be excited due to edge of the rectangular wave since the edge of the rectangular wave is steep.

Therefore, as shown in FIG. **9**A and FIG. **9**B, preferably, the stirring waveform is generated based on a signal whose frequency is less than the natural frequency of the higher order mode of the membrane **12**, that is, the stirring waveform does not have the natural frequency of the higher order mode. FIG. **9**A is a diagram for illustrating a sine wave including only a specific frequency component, and the frequency (=1/T) thereof is less than the natural frequency f**11** of the secondary mode.

Another example of the preferable stirring waveform is shown in FIG. **9**B. FIG. **9**B is diagram for illustrating a waveform generated by performing low-pass filtering on the rectangular wave shown in FIG. **7** at a frequency less than the secondary natural frequency f**11**, where the wave form does not include the frequency component of the higher order mode. The aforementioned examples are not limiting examples, and the stirring waveform may be an arbitrary waveform in which the frequency component of the higher order mode has been cut off.

According to NonPatent Document 1, the natural frequency f**01** of the basic mode is expressed by formula (1) shown below.

[Math. 1]

$$f_{01} = \frac{0.467t}{r^2}\sqrt{\frac{E}{\rho(1-\sigma^2)}} \tag{1}$$

Wherein, "t" indicates a thickness of the membrane **12**, "r" indicates a radius of the membrane **12**, "ρ" indicates a density of the material forming the membrane **12**, and "E" and "σ" respectively indicate a Young's modulus, and a Poisson's ratio of the material forming the membrane **12**.

The natural frequency of the basic mode and the natural frequency of the higher order mode with respect to the membrane **12** can be estimated in advance based on the aforementioned formula (1) and table 1. However, the values are estimated assuming that the membrane is in the atmosphere. If one side surface of the membrane is in contact with liquid as the case of the present embodiment, actual values of the natural frequencies vary.

The values of the natural frequencies vary in accordance with amount of the liquid (as described with reference to FIG. **12**). However, for example, according to NonPatent Document 2, approximate values of the natural frequencies can be calculated by formula (2) shown below. Here, *Vibration of Circular Membranes in Contact with Water,* 1994 Journal of Sound and Vibration 178(5), pp. 688-690 is referred to as NonPatent Document 2.

[Math. 2]

$$f_{W01} = \frac{f_{01}}{\sqrt{1+\frac{\rho w\cdot r}{\rho\cdot t}\Gamma}} \tag{2}$$

Wherein, "fw**01**" indicates the natural frequency of the basic mode in a case where one side surface of the membrane is in contact with liquid, "ρw" indicates a density of the water, "Γ" indicates a constant referred to as NAVMI coefficient. It is known that "Γ" is 0.746313 at f**01**. For example, when using a SUS whose diameter (diameter inside fixed portion) is approximate 10 mm and thickness is approximate 50 μm as the membrane **12**, "fw**01**" is approximate 30% of "f**01**".

Also, according to a similar calculation using NAVMI coefficient disclosed in NonPatent Document 2, the natural frequency of the higher order mode in the liquid is approximate 45% to 60% of the natural frequency in the atmosphere.

As described above, when the stirring waveform is generated based on a signal whose frequency is less than the natural frequency of the higher order mode in the membrane **12**, a distribution of vibration intensities in the surface of the membrane **12** and unevenness in the stirring can be suppressed.

Although, hereinabove, the membrane **12** is a disk whose edge is fixed, the membrane **12** may be a rectangular plate whose edge is fixed. It is known that the rectangular plate has a plurality of natural vibration modes similarly to the disk, and the natural frequency "fjk" thereof can be calculated by using "j" and "k", where "j" indicates a number of nodes in vertical direction and "k" indicates a number of nodes in horizontal direction.

FIG. **10** is a diagram for illustrating the natural vibration modes of the rectangular plate whose edge is fixed. In FIG. **10**, the natural vibration modes of the rectangular plate are schematically illustrated in a case where "j" of the natural vibration mode "fjk" is "1"-"3" and "k" of the natural vibration mode "fjk" is "1"-"3". In FIG. **10**, outer rectangular indicate the plate while lines inside the outer rectangular indicate nodes of vibration. Phases of vibrations of adjacent nodes are reverse to each other.

Here, the vibration of the plate in a case where "j"=1 and "k"=1 is referred to as a basic mode, and respective vibrations other than the basic mode are referred to as higher order modes. As shown in FIG. **10**, the plate includes no nodes of vibration only when the plate vibrates in the basic mode.

According to NonPatent Document 1, the natural frequency f**11** of the basic mode is expressed by formula (3).

[Math. 3]

$$f_{11} = 0.453t\left(\frac{1}{l^2}+\frac{1}{m^2}\right)\sqrt{\frac{E}{\rho(1-\sigma^2)}} \tag{3}$$

Wherein, "l", "m" and "t" respectively indicate a length, a width and a thickness of the membrane **12**, "ρ" indicates a density of the material forming the membrane **12**, and "E" and "σ" respectively indicate a Young's modulus, and a Poisson's ratio of the material forming the membrane **12**.

The natural frequency of the basic mode and the natural frequency of the higher order mode with respect to the membrane **12** can be estimated in advance based on the aforementioned formula (3) and FIG. **10**.

Also, the membrane **12** may be a slit plate, where both edges of the slit plate are fixed. It is known that the slit plate fixed at both edges thereof has a plurality of natural vibration modes. When one of a length and a width of the slit plate is much longer than the other, the vibration of the slit plate can be regarded as not a vibration in two dimensional direction, but a vibration in one dimensional direction. The natural frequency "fi" of the slit plate can be calculated by using a number "i" of loops of vibration.

FIG. **11** is a diagram for illustrating the natural vibration modes of the slit plate fixed at both edges thereof. FIG. **11** schematically illustrates vibrations of the slit plate, where "i" of the natural frequency "fi" is "1"-"3". Here, the vibration of the slit plate at "i"=1 is referred to as a basic mode, and respective vibrations other than the basic mode are referred to as higher order modes. As shown in FIG. **11**, the slit plate does not include any nodes of vibration except the fixed both edges only when the slit plate vibrates in the basic mode.

According to NonPatent Document 1, the natural frequency f**1** of the basic mode is expressed by formula (4).

[Math. 4]

$$f_1 = \frac{3.56}{l^2}\sqrt{\frac{EJ}{\rho A}} \tag{4}$$

Wherein, "l" indicates a length of the membrane **12**, "A" and "J" respectively indicate cross sectional area of the membrane **12** and cross sectional secondary moment of the cross section, "ρ" indicates a density of the material forming the membrane **12**, and "E" indicates a Young's modulus of the material forming the membrane **12**.

The natural frequency of the basic mode and the natural frequency of the higher order mode with respect to the membrane **12** can be estimated in advance based on the aforementioned formula (4) and FIG. **11**.

As described above, similarly to the case of the disk, when the stirring waveform is generated based on a signal whose frequency is less than the natural frequency of the higher order mode in the membrane **12**, a distribution of vibration intensities in the surface of the membrane **12** and unevenness in the stirring can be suppressed in a case where the membrane **12** is a rectangular plate whose edge is fixed or a slit plate fixed at both edges thereof.

Second Variation of First Embodiment

Other appropriate examples of the stirring waveform are shown in the second variation of the first embodiment. Descriptions on elements or the like that have substantially similar functions and configurations to those described above may be omitted in the second variation.

The frequency (=1/T) of the stirring waveforms shown in FIG. **9**A and FIG. **9**B may be coincident with the natural frequency of the basic mode of the membrane **12**. In this case, the stirring can be most efficiently performed since the membrane **12** can be vibrated with significantly low driving voltage and the precipitating particles **350** exist in the stirred liquid without irregularities in the dispersion.

However, the natural frequency of the membrane **12** varies depending on the amount of the liquid **300** held in the liquid chamber **11**. FIG. **12** is a graph for illustrating an example measuring result of the natural frequency of the basic mode in a prototype liquid droplet forming apparatus by using a laser Doppler vibration meter (LV-1710, manufactured by "ONO SOKKI" corporation). Additionally, in the prototype liquid droplet forming apparatus, a ring-shaped push-type piezoelectric element (material C-2, manufactured by "FUJI CERAMIC" corporation) is used as the piezoelectric element **13** and a nozzle-type SUS pinhole whose diameter is 35 μm (manufactured by Edmund optics corporation) is used as the membrane **12**.

In FIG. **12**, line (**1**) corresponds to the liquid amount 50 μl, line (**2**) corresponds to the liquid amount 40 μl, line (**3**) corresponds to the liquid amount 30 μl, line (**4**) corresponds to the liquid amount 20 μl, line (**5**) corresponds to the liquid amount 10 μl, and line (**6**) corresponds to the liquid amount 0 μl (no liquid), where the respective lines indicates relationships between the vibration intensity and the frequency at respective amounts of liquid held in the liquid chamber.

As shown in FIG. **12**, the natural frequency of the basic mode at the liquid amount 50 μl (shown as line (**1**) in FIG. **12**) is less than the natural frequency of the basic mode at the liquid amount 10 μl (shown as line (**5**) in FIG. **12**) by approximate 40%. It is difficult to keep the frequency of the stirring waveform to be coincident with the natural frequency of the basic mode since the liquid amount reduces as the droplets are formed, or reduces due to aridity.

Therefore, a range of variance of the natural frequency of the basic mode that varies depending on the liquid amount is preferably included in a range between a first frequency and a second frequency that is different from the first frequency, where the frequency of stirring waveform varies in the range between the first frequency and the second frequency. Thus, even if the natural frequency of the basic mode varies depending on the liquid amount, the membrane **12** can be efficiently vibrate at the natural frequency of the basic mode since the natural frequency of the basic mode only varies in a range from the first frequency to the second frequency.

FIG. **13** is a diagram for schematically illustrating an example stirring waveform whose frequency varies in a range from the first frequency to the second frequency. Wavelength in the stirring waveform continuously varies from a wavelength corresponding to the first frequency f**1** (=1/T**1**) to a wavelength corresponding to the second frequency f**2** (=1/T**2**), where more wave lengths than the wave lengths shown in FIG. **13** are included in the actual stirring waveform.

Additionally, in FIG. **13**, although the stirring waveform is shown as a continuously modulated sine wave signal, this is not a limiting example. A rectangular wave signal or triangular wave signal on which the low-pass filtering is performed may be used. And the signal does not have to be continuously modulated, but may be modulated by switching the frequency of the modulation step by step. Also, a similar effect of the stirring can be expected by using a type of beat signal in which a plurality of frequency components are mixed instead of using a waveform in which the frequency is swept.

As described above, preferably, the stirring waveform includes the natural frequency of the basic mode of the membrane **12**, which enables to perform efficient stirring with small energy.

Also, more preferably, the frequency of the stirring waveform varies from the first frequency to the second frequency, where the natural frequency of the basic mode of the membrane **12** is within a range between the first frequency to the second frequency. In this case, the stirring can be stably performed even when the natural frequency of the membrane **12** varies depending on the liquid amount in the liquid chamber **11**.

As shown in FIG. **14**, in order to uniformly stir the liquid in the liquid chamber, a second stirring waveform **31**B, other than a first stirring waveform **31**A for vibrating the membrane **12** without forming the droplet, may be used, where a voltage of the second stirring waveform **31**B is greater than the voltage of the first stirring waveform **31**A. In FIG. **14**, since the driving voltage V**4** of the second stirring waveform **31**B is greater than the driving voltage V**3** of the first stirring waveform **31**A, the membrane **12** vibrates more strongly to stir the liquid in the liquid chamber **11** more uniformly.

In this case, unexpected droplets may be formed due to the strong vibration of the membrane **12**. Therefore, as shown in FIG. **15**A, in a case where the second stirring waveform **31**B is used for stirring, preferably, the stirring is performed after moving the liquid droplet forming apparatus **10** to a non-drawing region E**2** so as to prevent the unexpected droplet dropping on the drawing region E**1**. The unexpected droplet **310** may drop on the non-drawing region E**2** without causing any trouble. Additionally, as shown in FIG. **15**B, in a case where the first stirring waveform **31**A is used for the stirring, the stirring may be performed when the liquid droplet forming-apparatus **10** is located in the drawing region E**1**.

A method, in which a member whose natural frequency is greater than the natural frequency of the membrane **12** is used for the stirring, is also preferable. By using the member whose natural frequency is greater than the natural frequency of the membrane **12**, a problematic tendency that the precipitating particles **350** are likely to accumulate at edge portion of the bottom of the liquid chamber **11** is improved, which enables to uniformly stir the liquid in the liquid chamber **11**.

For example, as shown in FIG. **16**, wall of the liquid chamber **11** may be made thick to become greater than the membrane **12**, and the wall may be vibrated. In this case, since the wall forming a part of the liquid chamber **11** vibrates as shown as "A" in FIG. **16**, the edge portion of the membrane **12** vibrates as much as the center portion, which is exposed in the liquid chamber **11**, to improve the problematic tendency that the precipitating particles **350** are likely to accumulate at edge portion of the bottom of the liquid chamber **11**. Additionally, "B" shown in FIG. **16** schematically indicates a vibration when only membrane **12** is vibrated and the wall of the liquid chamber **11** is not vibrated for purpose of comparison.

Third Variation of First Embodiment

In the third variation of the first embodiment, an example liquid droplet forming apparatus including a liquid amount detection unit will be described. Descriptions on elements or the like that have substantially similar functions and configurations to those described above may be omitted in the third variation.

FIG. **17**A and FIG. **17**B are cross sectional views for illustrating examples of the liquid droplet forming apparatus of the third variation of the first embodiment including the liquid amount detection unit. In the liquid droplet forming apparatus **10**A shown in FIG. **17**A, a plurality of electrodes **15** as the liquid amount detection unit are disposed at inside wall surface of the liquid chamber **11**, where the electrodes **15** are arranged in a depth direction of the liquid chamber **11**. When using a conductive liquid as the liquid **300**, the amount of the liquid **300** can be detected by finding conduction or resistance value between the electrodes **15**.

In the liquid droplet forming apparatus **10**B shown in FIG. **17**B, a light-emitting element **16** and a position sensor **17** are located at the upper side of the liquid chamber **11**, where the light-emitting element **16** and the position sensor **17** serve as the liquid amount detection unit. The position sensor **17** is located at a position where the position sensor can receive a light emitted from the light-emitting element **16** and regularly reflected at a surface **300**A or a surface **300**B of the liquid **300**. Thus, a distance between a position at which the position sensor **17** receives the light and the surface of the liquid **300** can be calculated based on the principal of triangulation. However, the configuration of the liquid amount detection unit is not limited to the configurations shown in FIGS. **17**A and **17**B. Various known method for measurement of distance or detection of liquid surface may be used for achieving the liquid amount detection unit.

The driving device **30** may be configured so as to vary the stirring waveform based on an output signal of the liquid amount detection unit. For example, the driving device **30** selects an appropriate frequency based on the output signal of the liquid amount detection unit regarding the liquid amount with reference to a lookup table, thereby outputting the stirring waveforms as shown in FIG. **9**A and FIG. **9**B.

Also, the detection result of the liquid amount detection unit may be used for generating the stirring waveform shown in FIG. **13** in which the frequency is swept. In this case, the first frequency and the second frequency are determined based on the detection result of the liquid amount detection unit.

As described above, the liquid droplet forming apparatus **10**A and **10**B of the third variation of the first embodiment respectively include the liquid amount detection unit for detecting the amount of the liquid **300**, and the driving device **30** of the third variation of the first embodiment controls the stirring waveform based on the detection result of the liquid amount detection unit. Thus, the stirring can be stably performed even when the natural frequency of the membrane **12** varies depending on the liquid amount since the stirring waveform adapted to the variance of the natural frequency can be output.

Fourth Variation of First Embodiment

In the fourth variation of the first embodiment, an example liquid droplet forming apparatus for providing the stirring waveform with a certain time interval will be described. Descriptions on elements or the like that have substantially similar functions and configurations to those described above may be omitted in the fourth variation.

Preferably, the driving device **30** does not continue to input the stirring waveform during a period in which the droplet is not formed, but periodically inputs the stirring waveform with a certain time interval TB**1** as shown in FIG. **18**. If the stirring waveform is continued to be input, power consumption increases and the membrane **12** is heated due to the continuous vibration, which may cause an adverse effect depending on a type of the liquid **300** including the precipitating particle **350**. In particular, in a case where the liquid **300** includes cells, the heating shall be avoided since high temperature causes damage to the cells. Therefore, unnecessary stirring shall be avoided.

Further, the time interval TB**1** in the stirring is preferably set in accordance with a property of the precipitating particle **350** or a property of a solvent for dispersing the precipitating particles **350**. It is known that a precipitating speed of a particle can be expressed by Stokes formula shown as formula (5).

[Math. 5]

$$v = \frac{2r^2 g}{9\eta}(\rho - \delta) \tag{5}$$

Wherein, "v" indicates the precipitating speed of a particle, "g" indicates gravity acceleration, "r" indicates a radius of the particle, "η" indicates a viscosity of the solvent, "ρ" indicates a density of the particle, and "δ" indicates a density of the solvent. For example, when fine particles of polystyrene whose radius is 5 μm and whose density is 1050 kg/m^3 disperse in the water, the precipitating speed "v" is approximate 3 μm/s. Depending on the density of the particle, generally a thickness of the membrane **12** is 10-100 μm, and adverse effects such as a nozzle clogging start to be caused when the particles totally precipitate by approximate several μm.

Therefore, preferably, the time interval TB**1**, with which the stirring is performed, is approximate equal to or less than "1" sec. When the precipitating speed "v" is approximately 3 μm/s and the time interval TB**1** is approximate equal to or less than "1" sec, the particles totally precipitate by approximate equal to or less than 3 μm during the stirring is not performed. Hence, the nozzle clogging, etc., can be suppressed.

For example, the user may directly set the time interval TB**1** in the liquid droplet forming apparatus. Or, the liquid droplet forming apparatus may have a function for internally performing the aforementioned calculation to automatically calculate the appropriate time interval TB**1** with which the stirring is performed in response to the user inputting basic data (e.g., data for indicating a type of the solvent, the density and the viscosity thereof).

As described above, in the liquid droplet forming apparatus of the fourth variation of the first embodiment, the driving device **30** periodically gives the membrane **12** the stirring waveform with a certain time interval. Thus, the stirring for preventing the precipitating particles **350** from precipitating can be performed with small energy during a period in which the droplet is not formed. Preferably, the certain time interval is set based on a property of the precipitating particle **350**, and the like.

<Prototyping>

In the following, a test result of a prototype of the liquid droplet forming apparatus **10** will be described, by which the liquid **300** including the precipitating particles **350** is ejected. In the prototype of the liquid droplet forming apparatus **10**, a bending ring piezo element (CMBR03 manufactured by Noriac Corporation) is used as the piezoelectric element **13**, and a SUS pinhole whose nozzle diameter is 50 μm (#39-879, manufactured by Edmund optics Corporation) is used as the membrane **12**. The test has been performed in order to validate the effect of the stirring of the precipitating particles **350** through the vibration of the membrane **12**, where the effect of the stirring of the prototype of the liquid droplet forming apparatus **10** has been validated by using an observation apparatus **500** shown in FIG. **19**.

The observation apparatus **500** observes inside the liquid camber **11** of the liquid droplet forming apparatus **10** by a CCD **502** with a lens **501** disposed over the liquid droplet forming apparatus **10**. Also, an arbitrary pattern-shaped droplet **310** is ejected, where the droplet **310** including the precipitating particles **350** is ejected on a preparation **504** disposed on an automatic driven stage **505**.

The stirring and the ejection are performed by inputting the stirring waveform and the ejection waveform from the driving device **30** to the piezoelectric element **13**. At this time, a dispersion state of the liquid **300** including the precipitating particles **350** filled in the liquid chamber **11** is observed through the CCD **502**. Also, a number of the precipitating particles **350** included in each droplet **310** is calculated by ejecting the droplets **310** linearly arranged on the preparation **504**. Approximate 30 μl of liquid solution (Thermo Scientific, Duke 2010A) including particles of polystyrene whose diameters are approximate 10 μm is filled in the liquid chamber **11** as the liquid **300** including the precipitating particles **350**.

Table 2 indicates an observation result of a stirring state of the precipitating particles **350** in the liquid chamber **11**, where the stirring has been performed by using three different stirring waveforms that are a sweep waveform including the natural frequency of the basic mode, a sweep waveform including the natural frequency of the higher order mode, and no waveform (not inputting any signals). Here, the sweep waveform including the natural frequency of the basic mode means a waveform in which a range of frequency approximate 18 kHz-21 kHz is swept in approximate 0.01 sec. Also, the sweep waveform including the natural frequency of the higher order mode means a waveform in which a range of frequency approximate 69 kHz-71 kHz is swept in approximate 0.01 sec.

TABLE 2

	SWEEP WAVEFORM (INCLUDING NATURAL FREQUENCY OF BASIC MODE)	SWEEP WAVEFORM (INCLUDING NATURAL FREQUENCY OF HIGHER ORDER MODE)	NO WAVE-FORM
VOLTAGE [V]	3	3	—
FREQUENCY [kHz]	18~21	69~71	—
STIRRING STATE	○	x	x

According to table 2, when using the sweep waveform including the natural frequency of the basic mode, a stirring state of a totally uniform stirring has been observed. However, when inputting no signals, the particles have precipitated. And when using the sweep waveform including the natural frequency of the higher order mode, a distribution of vibration intensity in the surface of the membrane **12** occurs and a biased dispersion of the particles, which is schematically shown in FIG. **20**A, has been observed. Additionally, in FIG. **20**A, a reference "**11***a*" indicates the inside wall of the liquid chamber **11**.

The range of frequency in the basic mode is approximate 18 kHz-21 kHz, and the range of frequency in the higher order mode is approximate 69 kHz-71 KHz. Therefore, the frequency of the higher order mode is approximate 3.5 times higher than the frequency of the basic mode. This corresponds to the natural frequency f**21** shown in table 1, where a magnification ratio between the natural frequencies of the basic mode and the frequency f**21** is "3.43".

According to Bernoulli's theorem, the particles tend to be drawn to the loops of vibration since the pressure reduces in an area where a flow speed becomes low in comparison to adjacent area, whereas the flow speed is high in the loops of vibration, that is, the intensity of vibration is greater in the loops of vibration. The biased dispersion of the particles shown in FIG. **20**A is observed since the particles are drawn from positions shown as nodes in FIG. **8** to areas "C" divided with the nodes B shown in FIG. **20**B at the natural frequency f**21**. Thus, when using the stirring waveform whose frequency corresponds to the natural frequency of the higher order mode, non-uniform dispersion state has been observed.

Then, as shown in FIG. **21**, the stirring waveform **31**C and the ejection waveform **32**C have been alternately input to eject the droplet **310** including the precipitating particles **350** onto the preparation **504**. The numbers of the precipitating particles **350** included in the ejected droplets **310** have calculated in order to validate a suppressing effect of the variance of the number of the precipitating particles **350** in the droplet **310**.

In this case, the ejection has been performed at 2 kHz, and a simple trapezoid wave whose voltage is 50 V is used as the ejection waveform **32**C. Also, a sweep waveform including the natural frequency of the basic mode whose voltage Vs is 1.4 V and a stirring time (period) Ts is 0.3 sec. is used as the stirring waveform **31**C. The ejection has been started just after filling the liquid **300** including the precipitating particles **350** in the liquid chamber **11**.

Table 3 shows standard deviations of calculation results of the numbers of precipitating particles **350** in the droplet **310**, where the numbers of the precipitating particles have been calculated at respective timings of 0, 1, and 2 minutes passes from the ejection (the calculation has been performed 30 times at respective timings, 90 times in total: which is referred to as a first half) and the numbers of the precipitating particles have been calculated at respective timings of 4 and 8 minutes passes from the ejection (the calculation has been performed 30 times at respective timings, 60 times in total: which is referred to as a second half).

TABLE 3

	SWEEP WAVEFORM (INCLUDING NATURAL FREQUENCY OF BASIC MODE)		NO WAVEFORM	
VOLTAGE Vs [V]	1.4		0	
STIRRING TIME Ts [s]	0.3		0	
TIME PASSES FROM EJECTION [min]	0, 1, 2	4, 8	0, 2	4, 8
STANDARD DEVIATION [NUMBER OF PARTICLES]	2.2	2.1	2.8	3.9

According to table 3, when using the stirring waveform **31**C that is the sweep waveform including the natural frequency of the basic mode to stir the liquid **300**, there is not a significant difference between values of the standard deviations' in the first half and the second half. However, when inputting no signals, the standard deviation in the second half increases in comparison to the first half. The reason is considered that the non-uniform dispersion state of the precipitating particle **350** is caused due to precipitation of the precipitating particles **350** as the time passes in a case where the stirring is not performed, while the variance of the numbers of the precipitating particles **350** in the droplet **310** is unlikely to be observed just after the ejection since the dispersion state of the precipitating particles **350** is kept uniform.

As described above, in a case where the stirring has been performed, it has been observed that the standard deviation of the numbers of the precipitating particles **350** in the droplets **310** has not significantly varied even after the time passes. That is, suppression effect of the variance of the numbers of the precipitating particles **350** in the ejected droplets **310** due to the stirring using the vibration of the membrane **12** has been observed.

Herein above, although the invention has been described with respect to a specific embodiment for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art that fairly fall within the basic teaching herein set forth. The present application is based on Japanese Priority Application No. 2014-259121 filed on Dec. 22, 2014, Japanese Priority Application No. 2015-109677 filed on May 29, 2015, and Japanese Priority Application No. 2015-200822 filed on Oct. 9, 2015, the entire contents of which are hereby incorporated herein by reference.

What is claimed is:

1. A liquid droplet forming apparatus comprising:

a liquid holding part configured to hold a liquid including precipitating particles;

a film member configured to be vibrated so as to eject the liquid held in the liquid holding part, wherein a nozzle is formed in the film member and the liquid is ejected as a droplet from the nozzle;

a vibrating unit configured to vibrate the film member; and

a driving unit configured to selectively apply an ejection waveform and a stirring waveform to the vibrating unit, wherein the film member is vibrated to form the droplet in response to applying the ejection waveform and the film member is vibrated to cause convective flows of the liquid in the liquid holding part without forming the droplet in response to applying the stirring waveform, the film member being vibrated due to the applied stirring waveform.

2. The liquid droplet forming apparatus as claimed in claim **1**, wherein the stirring waveform is generated based on a signal whose frequency is less than a natural frequency of a higher order mode vibration of the film member.

3. The liquid droplet forming apparatus as claimed in claim **1**, wherein the stirring waveform includes a frequency component corresponding to a natural frequency of a basic mode vibration of the film member.

4. The liquid droplet forming apparatus as claimed in claim **3**, wherein the stirring waveform is generated such that a frequency of the stirring waveform varies from a first frequency to a second frequency, and the natural frequency of the basic mode vibration is included between the first frequency and the second frequency.

5. The liquid droplet forming apparatus as claimed in claim **1**, further comprising a liquid amount detection unit configured to detect an amount of the liquid in the liquid holding part, wherein the driving unit controls the stirring waveform based on the detection result of the liquid amount detection unit.

6. The liquid droplet forming apparatus as claimed in claim **1**, wherein the driving unit periodically applies the stirring waveform to the vibrating unit with a certain time interval.

7. The liquid droplet forming apparatus as claimed in claim **6**, wherein the certain time interval is set according to a property of the precipitating particle.

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